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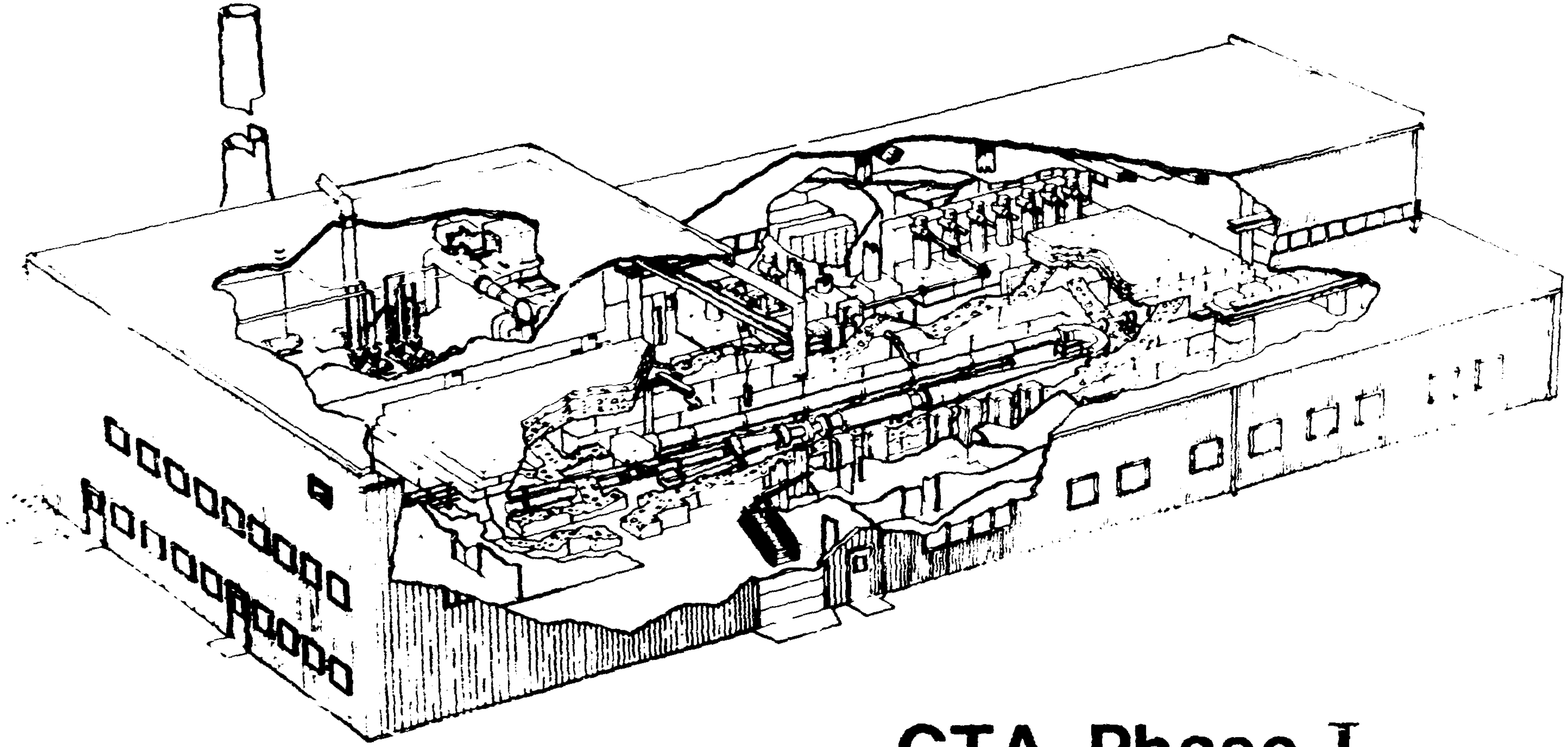
GTA Phase 1

BASELINE DESIGN REPORT

AUGUST 1986

GROUND TEST ACCELERATOR

LOS ALAMOS



GTA Phase I

GROUND TEST ACCELERATOR

LOS ALAMOS

GTA PHASE 1 BASELINE SYSTEM DESIGN REPORT

TABLE OF CONTENTS

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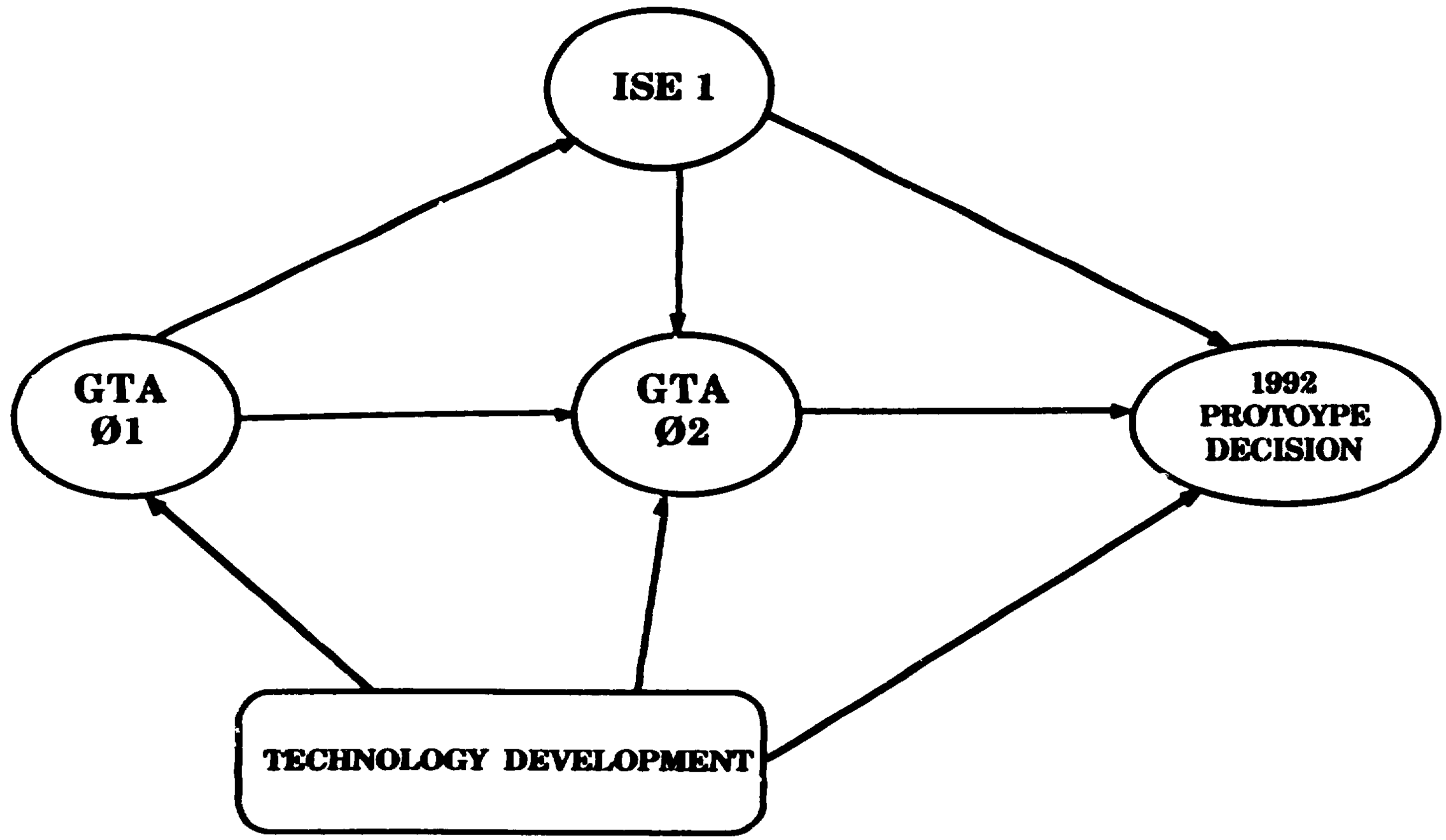
I. INTRODUCTION

I. ***INTRODUCTION***

The national Neutral Particle Beam (NPB) program has *two* objectives: 1) provide the necessary basis for a discriminator/weapon decision by 1992 (near term goal), 2) develop the technology in stages that lead ultimately to a NPB weapon (far term goal).

To meet these objectives and more directly the first objective a three pronged program is in progress. The essential components of this program are: 1) the Integrated Space Experiments (ISE-1 and Bear), 2) the Ground Test Accelerator (GTA), and 3) the Technology Program. The flight provides experience with NPB hardware in the space environment. The ground test accelerator is the test bed that permits us to advance the state-of-the-art under experimental conditions in an integrated automated system mode. The technology program executes the supporting research and development and specifically develops and tests components for the near term and for the systems.

To make the GTA program more cost effective it will serve two purposes. The ultimate goal is to support the 1992 decision while the intermediate goal is to support ISE-1. Both goals are satisfied by phasing GTA. The earlier Phase I supports ISE-1 and provides hardware and intermediate experience for Phase II. GTA Phase II is specifically designed to provide data towards the 1992 decision.



GTA CONTRIBUTES TO THE 1992 DECISION

The key parameters for GTA Phase 1 support ISE-1 goals.

Energy	50 MeV
Current (H°)	45 mA
Duty Factor	0.1% (operation)
Integrated System	Automated Controls

These parameters are an intermediate step between the existing technology base and the GTA Phase II requirements

GTA PHASE 1 MEETS ISE REQUIREMENTS AND IS AN INTEGRAL PART OF GTA PHASE 2

Divergence:	Stepping stone towards large bore, low divergence magnetic optics and neutralizer
	Medium bore, medium divergence, low energy
	Stepping stone towards precision beam sensing
	Development and first application of non-interceptive techniques (LRF, ICA, etc.)
	Experience with gas and foil neutralizers to make experimentally supported decision
Energy:	Operational experience and hardware for 50 MeV/100 mA (H^-) front end of GTA Phase 2
Neutral Current:	Operational experience and hardware for 50 MeV/50 mA (H°) current
Duty Factor:	Design and testing of components for 5% D.F.
	Operation of system at 0.1 D.F.
Integrated System:	Fully integrated and automated 50 MeV/50 mA NPB generator

GTA Phase 2 requirements are a significant increase over those of Phase 1

Divergence	Small
Energy	100 MeV
Duty Factor	5%
Particle	H^- (D^-?)

GTA PHASE 2 CONTRIBUTES TO 92 DECISION

Divergence:	Development and testing of large bore, high precision magnetic optics
	Development and testing of large bore foil (laser) neutralizer
	Development, testing and selection of best high precision beam sensing technique
Energy:	Operational experience with 100 MeV/100 mA accelerator (H^- or D^-)
Duty Factor:	Operational experience with entire machine at 5% D.F.
	Potential for testing of components at higher D.F.

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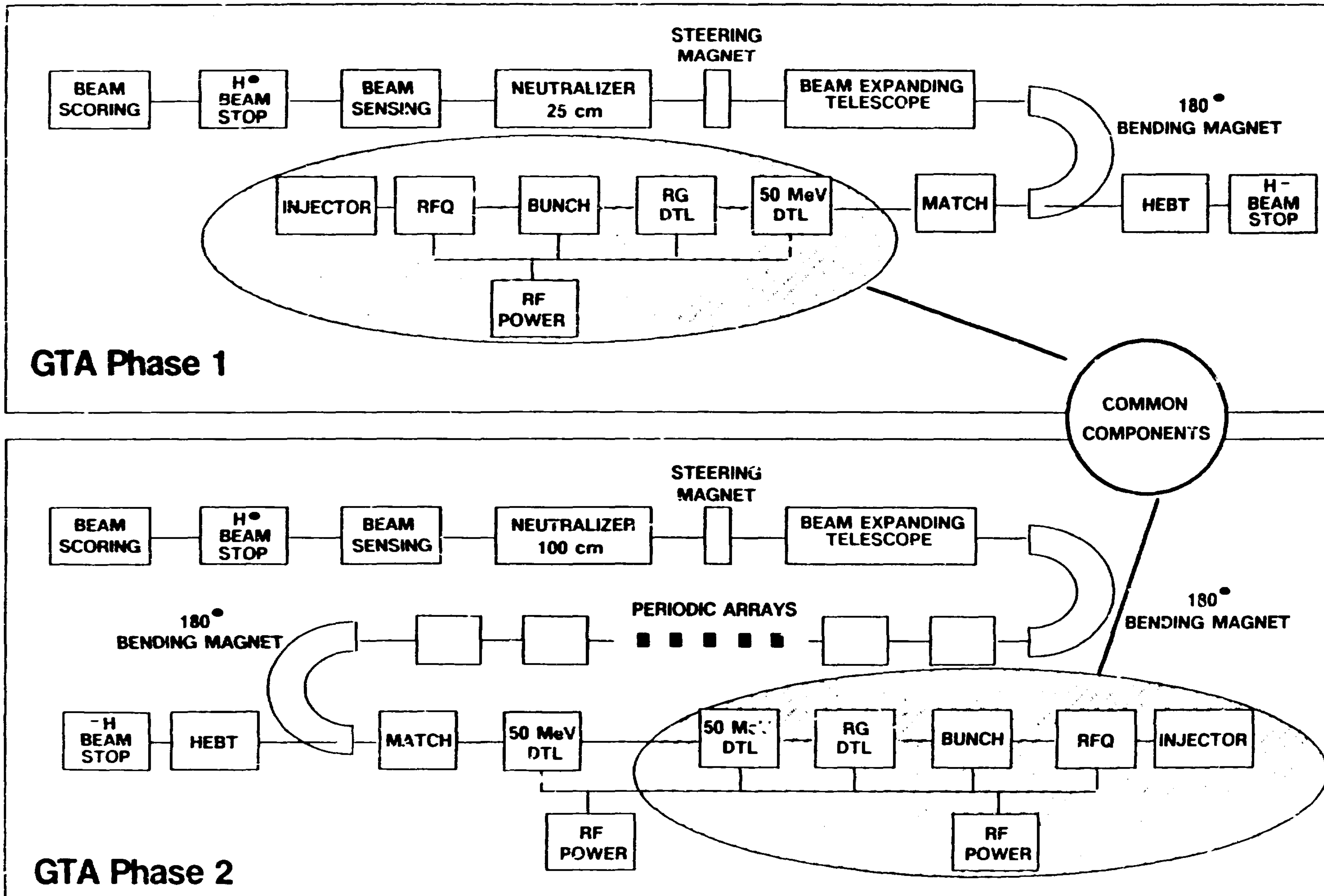
GTA Phase 1 Flows Into GTA Phase 2

In terms of hardware, GTA Phase I provides the "front end" of GTA Phase II. This means a 50 MeV/100 mA H^- accelerator, fully integrated and automated. In terms of experience, we will develop, design, build and test 30 cm, medium divergence magnetic output optics. This activity is considered extremely important as part of the learning curve towards one meter, low divergence optics required for GTA Phase II. Experience with a foil neutralizer serves also as a stepping stone towards the 100 cm GTA Phase II neutralizer. The development of interceptive beam sensing techniques will benefit primarily ISE-1, the development of non-interceptive techniques will support primarily GTA Phase II.

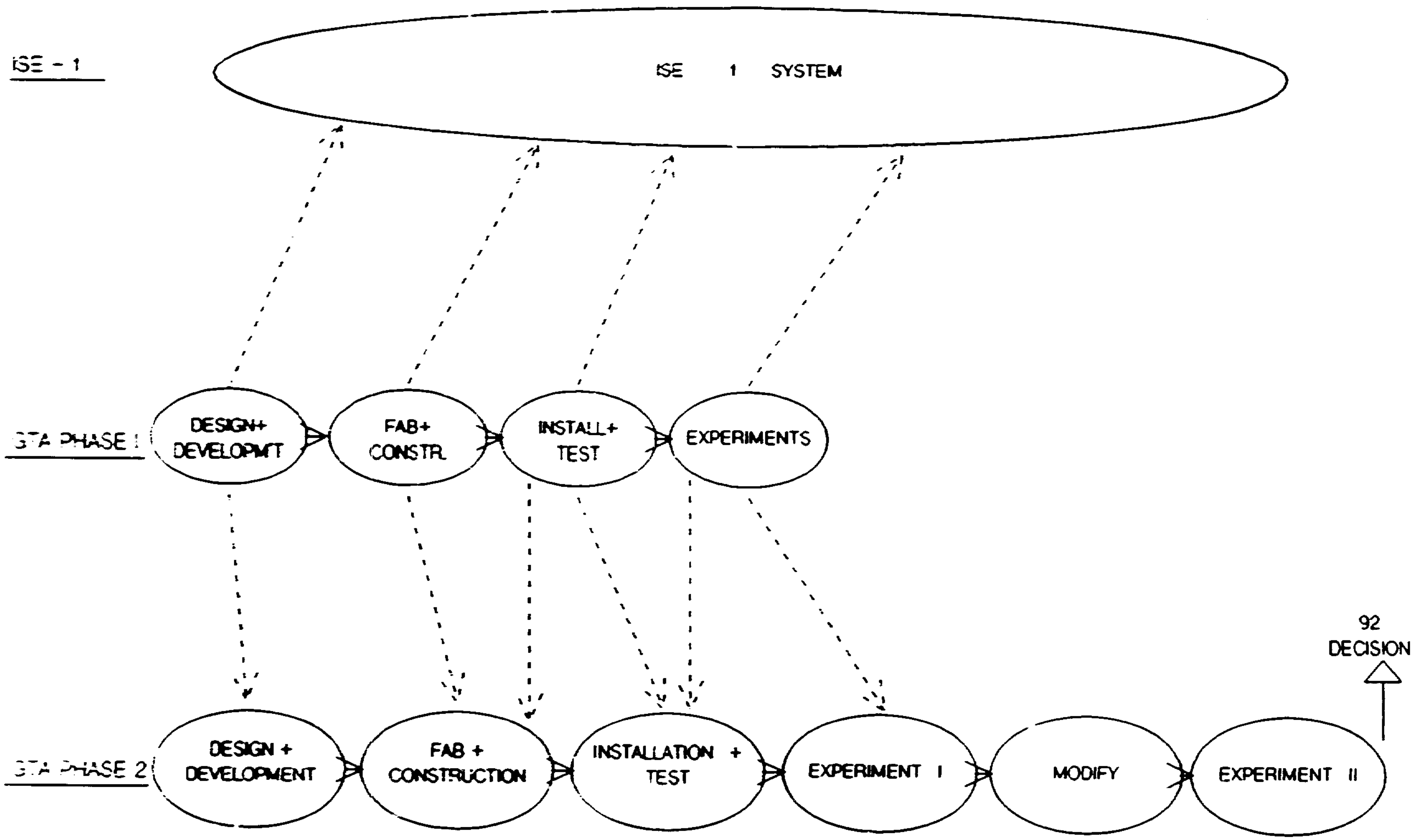
Evolution of GTA from Phase 1 to Phase 2



GTA Technology Is Available In Stages For ISE-1 And GTA-2.

Timely development, design and construction of GTA-1 will be essential for a successful ISE-1 program. It is mandatory that knowledge gained on GTA Phase 1 throughout the program be continuously provided to ISE-1. This technology transfer takes place in all areas, such as; code development and application, physics and engineering design of components, beam transport dynamics, experimental results of component testing at Los Alamos and Argonne National Laboratory, development of automatic control algorithms and experimental results of automatic control from ion source through the 50 MeV device.

We believe that through the active and timely participation of GTA Phase 1 the risk of the ISE-1 program will be significantly reduced and the road will be paved for GTA Phase 2 and thereby the 1992 decision.



GTA Phase I Schedule Supports ISE and 92 Decision

GTA Phase 1

II. System Overview

II. SYSTEM OVERVIEW

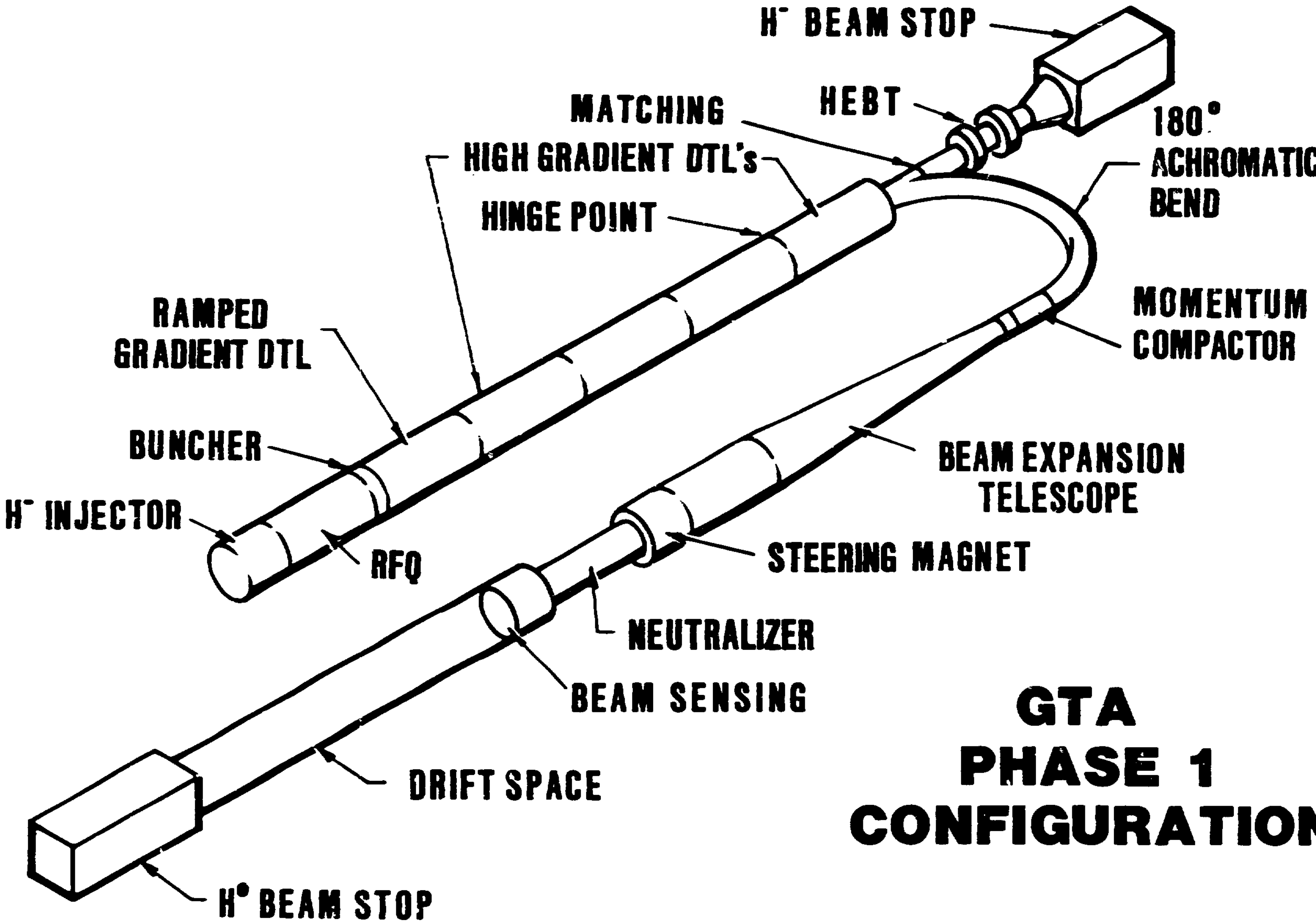
GTA PHASE 1 SYSTEM REQUIREMENTS

o Particle	H
o Output Energy	50 MeV (nominal)
o Accelerator Output Beam Current (H^-)	100 mA (nominal) or 20 mA (tune up capability)
o Output Beam Current (H°)	45 mA (nominal)
o Output Current Repeatability (H°)	± 5%
o Output Beam Shape	Ellipse with x & y diameter ratio between 0.8 and 1.0
o Output Beam Divergence (H°)	$\leq$25 μrad (θ/2) rms
o Output Beam Deflection (H°)	0 to 0.5°, one plane
o Steering Accuracy	<10 μrad
o Operating Frequency	425 MHz (nominal)
o Duty Factor	0.1% (operating), 5% (accelerator design value)*
o Beam Pulse Width (variable)	30 to 300 μs (operating), 2 ms (accelerator design value)*
o Pulse Repetition Rate	Accelerator compatible with 0.1% DF, NPB device 3 Hz maximum (also single pulse capability)
o Operating Ambient Temperature	Nominal room temperature, 70° ±3°F
o Operational Requirements	4 hours/day, 4 days/week, 46 weeks/year (736 hours/year), (~8 x 10^6 pulses/year at 3 Hz)
o Configuration	180° bend (Design compatible with hinge in DTL & telescope)
o Size	Basic accelerator design compatible with single shuttle launch (fit within 56'x14'x14'shuttle bay)
o Beam Height	1.52 m (60")

o System to be installed in TA-53, MPF-18

o Hardware will be space qualifiable wherever possible but is not required to be space qualified.

* Injector and LEBT, RFQ, buncher, RGDTL, 50 MeV DTL, vacuum system and cooling system shall be designed to fulfill the 5% duty factor and 2 ms pulse length requirement of GTA Phase 2.



GTA PHASE 1 CONFIGURATION

3. GTA PHASE 1 GENERAL DESCRIPTION

GTA Phase 1 provides a nominal 50 MeV neutral particle beam configured in a space compatible design. The initial H^- ion beam is accelerated by a radio-frequency (RF) linear accelerator, turned 180°, expanded twenty five times in transverse dimensions by the beam magnetic optics and stripped of excess electrons in a neutralizer to produce the resultant neutral particle beam.

The GTA Phase 1 System consists of the following systems:

- Accelerator
- Beam Magnetic Optics
- Neutralizer
- Beam Sensing
- Instrumentation and Controls
- RF Power
- Vacuum
- Cooling
- Facilities

The accelerator system includes the ion injector, radio-frequency quadrupole (RFQ), buncher/matcher, ramped gradient drift tube linac (RGDTL), six conventional drift tube linac (DTL) sections, the high energy beam transport (HEBT) and the H^- beam stop.

The beam magnetic optics includes the matching section, the 180° bend section, a momentum compactor, a beam expansion telescope and a beam steering magnet.

The neutralizer includes the gas neutralizer section and cryogenic panels simulate the space environment by removing the injected neutralizing gas. The neutralizer section is also compatible with the installation of a foil neutralizer when that development proves successful.

The beam sensing consists of all the output beam measurement equipment, the vacuum pipe for the beam drift space, the H^0 beam stop with its scoring system and beam stops for the H^+ and H^- beams.

Instrumentation and controls system includes the central control room, the system control and data analysis computers, the data transmission network and the data recording and processing equipment.

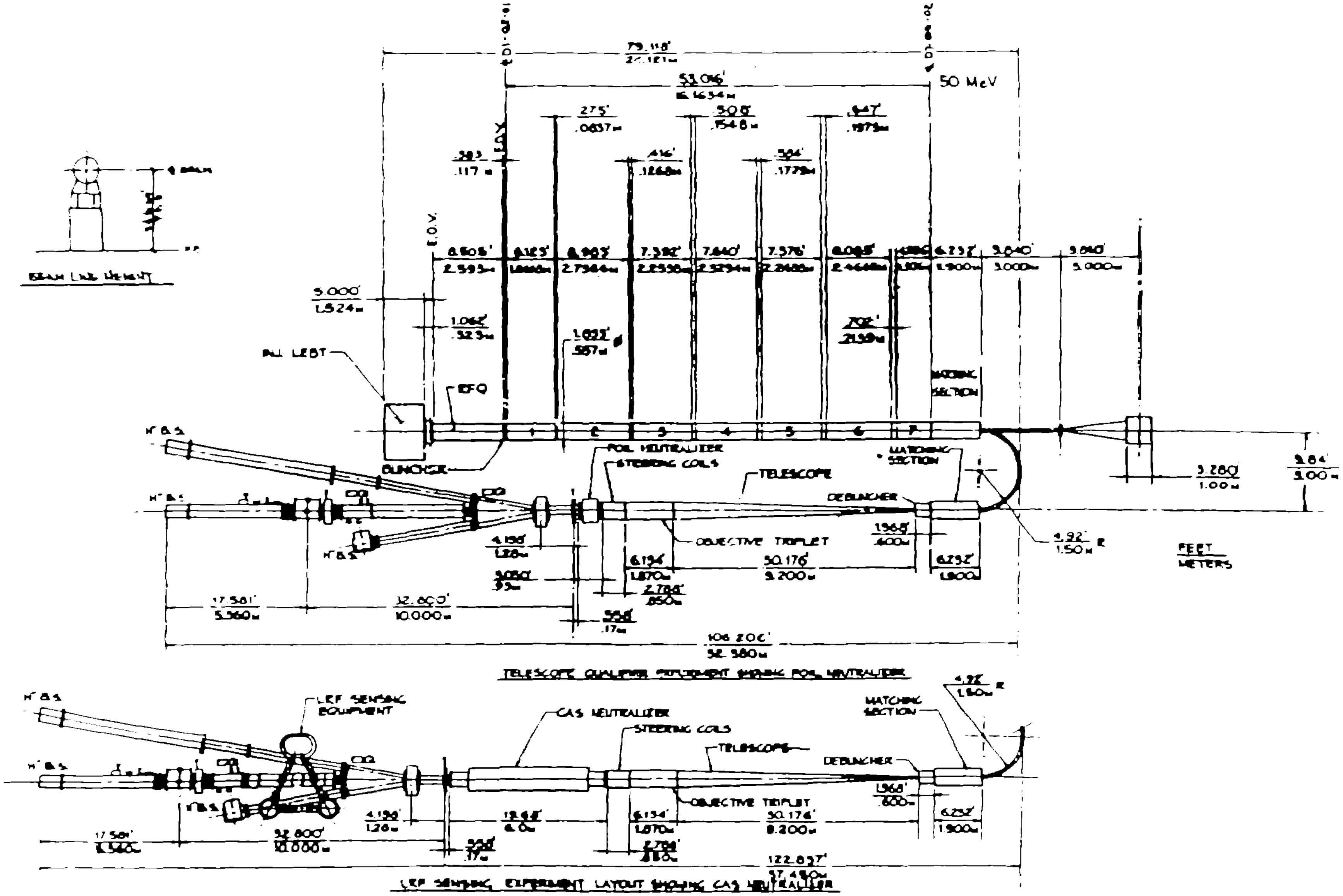
The RF power system provides sufficient RF power to drive the RFQ, buncher/matcher, RGDTL, the six DTL sections and the momentum compactor. Significant reserve power is available in the klystron RF system for overdrive.

The vacuum system provides the required pressures throughout the beam line and has provisions to quickly locate any leaks or outgassing.

The cooling system maintains critical components at the proper temperatures and removes heat generated during operations.

A mechanical alignment system provides the precision alignment references needed during assembly to ensure that the components are positioned within tolerance. It will also be used to recheck alignment during and after operation to determine any misalignments due to thermal drift, vibration, etc.

The Facilities System provides building MPF-18 (including additions to accomodate the GTA Phase 1 system) and the concrete radiation shielding. All required electrical power and its distribution, the cooling tower, and the required ambient air temperature control and ventilation are provided by the Facilities System.



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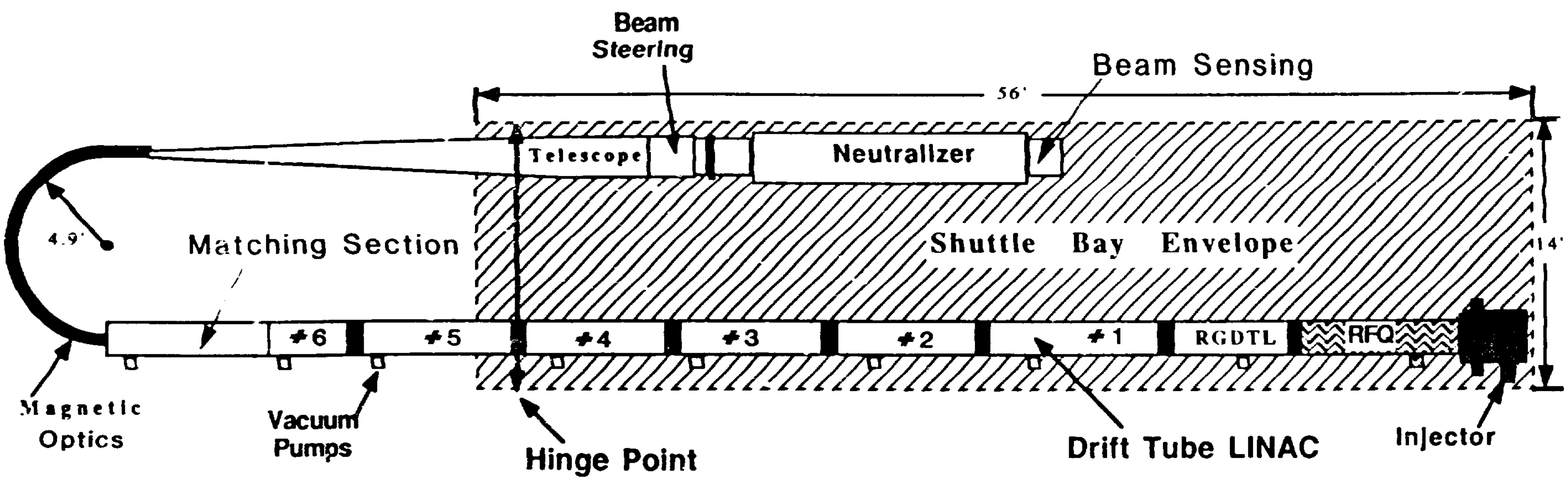
GTA-1 PHYSICS FOOTPRINT

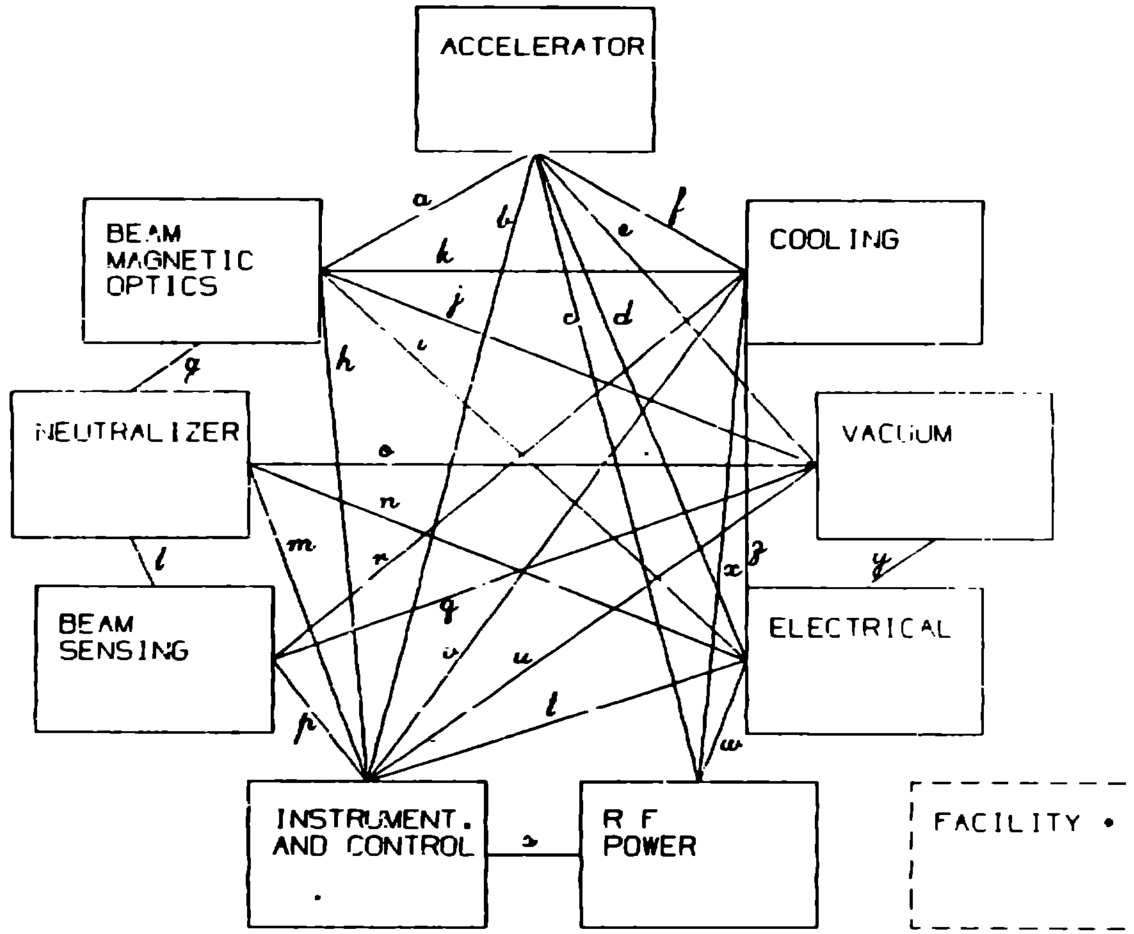
GTA-1 is Designed to Fit Within the Shuttle Envelope



GTA PHASE 1 INTERFACES

The system level interface shows the relationship of the nine GTA Phase 1 systems. The nine systems are connected by twenty-six interface ties. The facility has interfaces with all systems. A description of each of these interface ties and the relationship to each of the systems is provided in the GTA 1 interface tree, drawing number 112Y 254002. This tree provides the basis for creating interface control agreements (ICA) and interface control drawings (ICD).

(GTA-1)



SECOND LEVEL

• FACILITY WILL INTERFACE TO ALL OTHER COMPONENTS - THIRD LEVEL DIAGRAM IS NOT PROVIDED

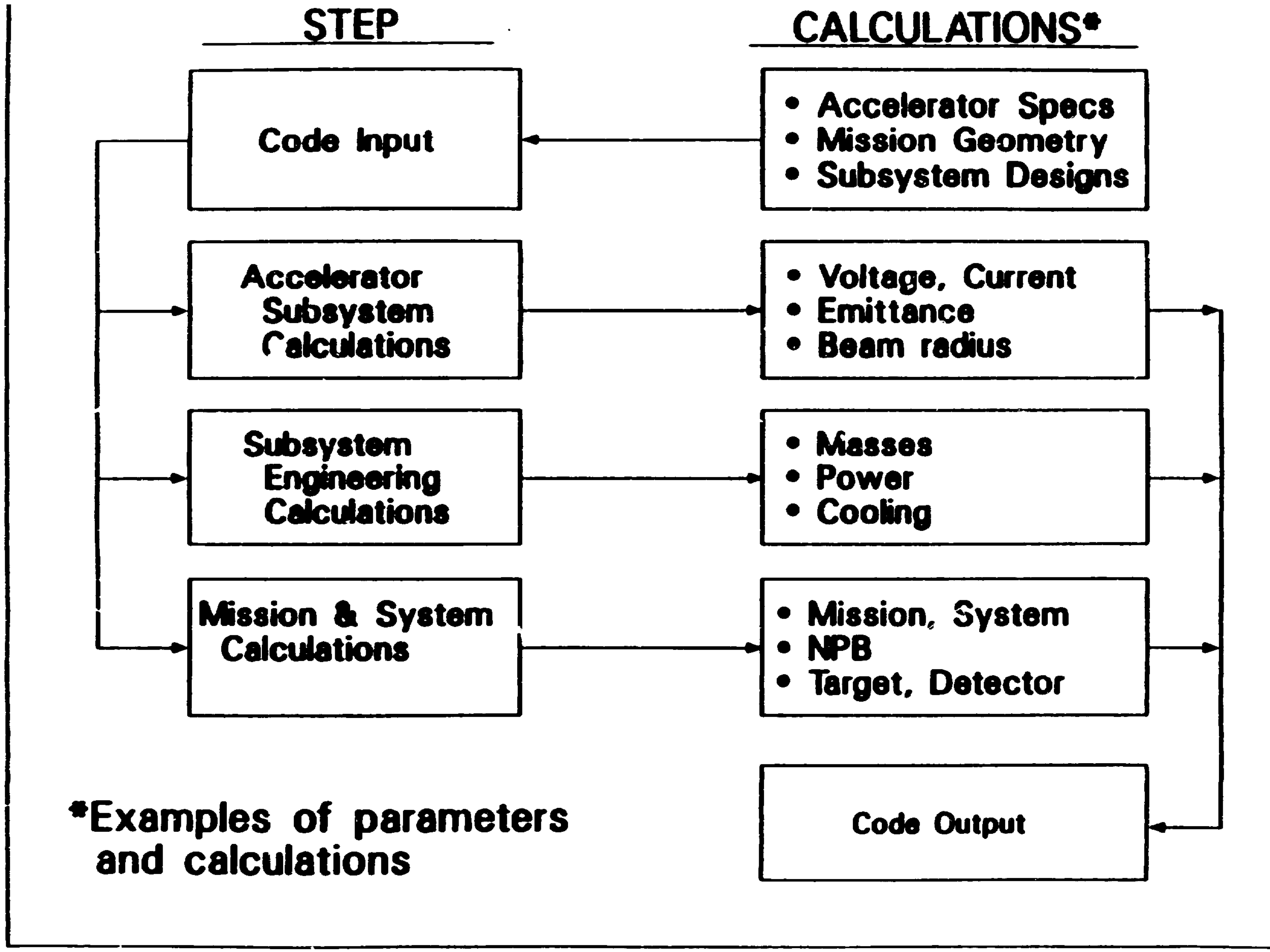
Systems Modeling - A systems model has been developed to analyze GTA designs and alternative ISE designs

* **Approach** - Focus on Engineering Tradeoffs
  - Use GTA as Code Benchmark
  - Develop Separate GTA/ISE Routines

* **Status** - ISESYS Code Description Complete
  - Program Coding and Analysis Continuing
  - Analysis Report to be Complete in FY86

S-4WP/86-81

Los Alamos


STEP
CALCULATIONS*
Code Input
• Accelerator Specs
• Mission Geometry
• Subsystem Designs
Accelerator Subsystem Calculations
• Voltage, Current
• Emittance
• Beam radius
Subsystem Engineering Calculations
• Masses
• Power
• Cooling
Mission & System Calculations
• Mission, System
• NPB
• Target, Detector
*Examples of parameters and calculations
Code Output

RELIABILITY ASSESSMENT

The GTA Phase 1 system is a one of a kind experimental device.

- o Objective
  - identify technical risk in system design and operation
  - identify and suggest methods of risk reduction such as redundancy, derated operation, etc.
  - utilize GTA Phase 1 system as test bed to demonstrate stepwise operational improvement in reliability performance
  - test contractor developed components
- o Approach
  - address reliability qualitatively due to experimental nature of system
  - identify single point failure design regions or mechanisms
  - determine level of risk in each subsystem

RELIABILITY ANALYSIS TECHNIQUES UNDER CONSIDERATION

May be used individually or in combination depending on data availability and depth of analysis.

- o Criticality Ranking
  - subsystem/component assigned defined technical risk levels: high, moderate, low
- o Failure Mode and Effects Analysis (FMEA)
  - examines failure modes of subsystem/component
  - details causes and effects on system
- o Fault Tree Analysis
  - identifies causal relationships between events that result in system failure
  - presents graphic display of failure relationships
  - starts with final event and traces backwards to initiating failure

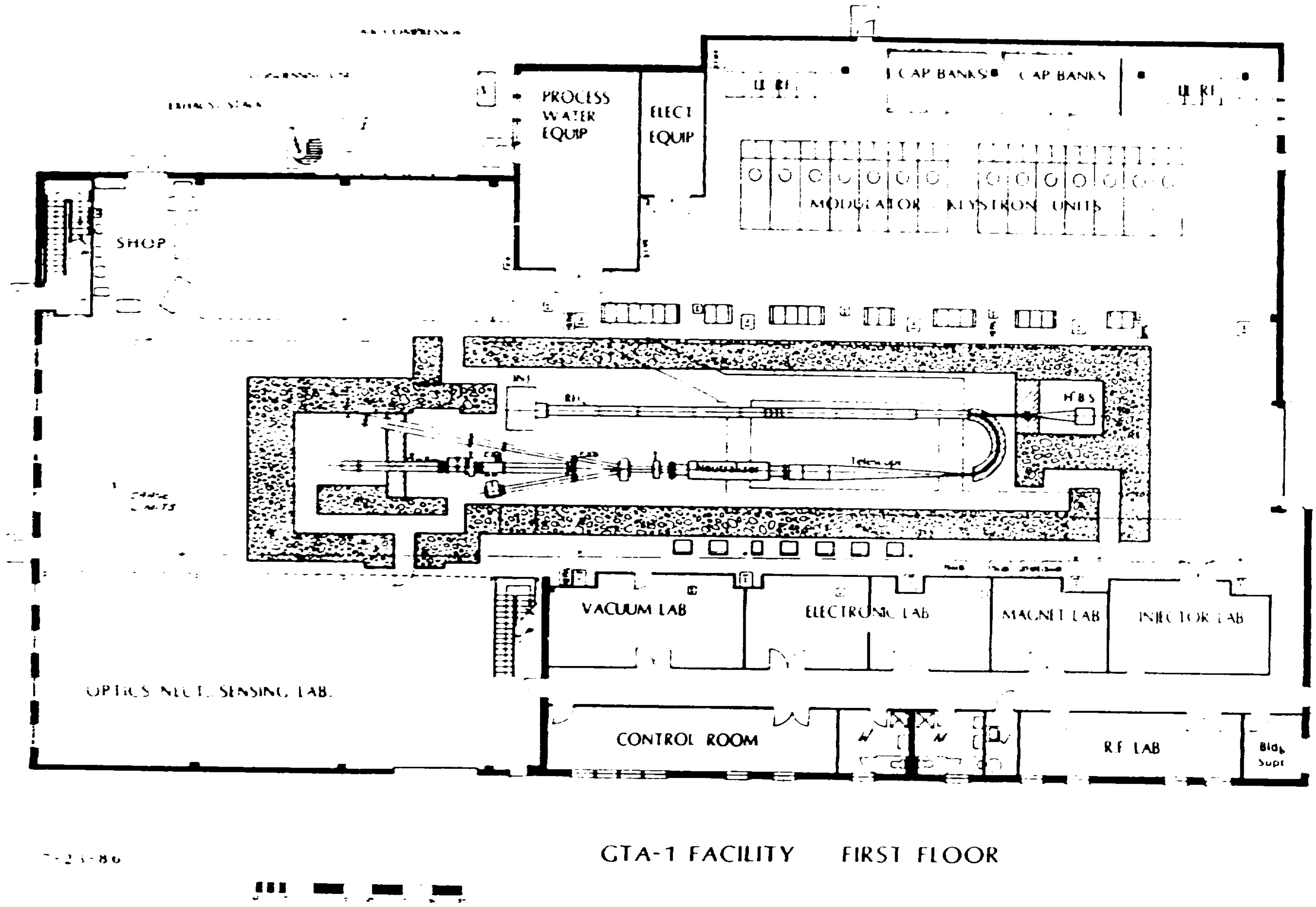
GTA PHASE 1 SYSTEM SPACE COMPATIBILITY

GTA Phase 1 system design guidelines

- Basic physics and electromagnetics designs functional in space environment
- Designs do not preclude ISE hardware space qualification
- GTA components will not be space qualified

GTA PHASE 1 FACILITY LAYOUT

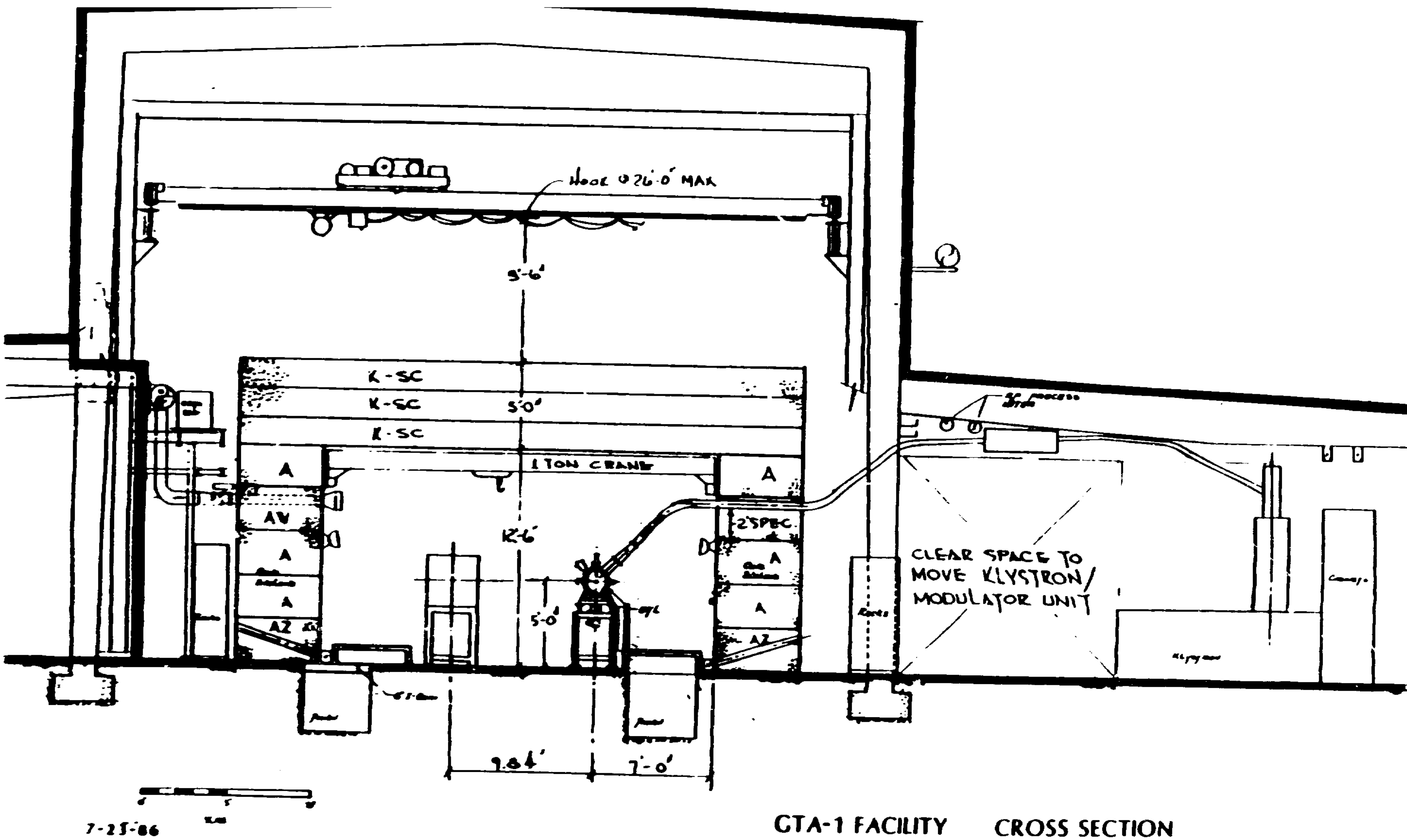
The facility consists of the existing building MPF-18, with a 10,000 square foot addition, located at Technical Area (TA)-53. With the addition, approximately 25,000 square feet of floor space is available to house the GTA Phase 1 neutral particle beam device and required support equipment. The first floor includes the beam vault, RF power, cooling system, and control room. Two mezzanines are provided in the building addition to provide laboratory space and the building mechanical equipment. Building ambient air temperature will be maintained at 70°, ±3°, F. Relative humidity level will be approximately 40%. Radiation monitoring equipment will measure the neutron and gamma radiation, both prompt and residual, as well as x-rays produced by the accelerator.



GTA-1 FACILITY FIRST FLOOR

GTA PHASE 1 FACILITY CROSS SECTION

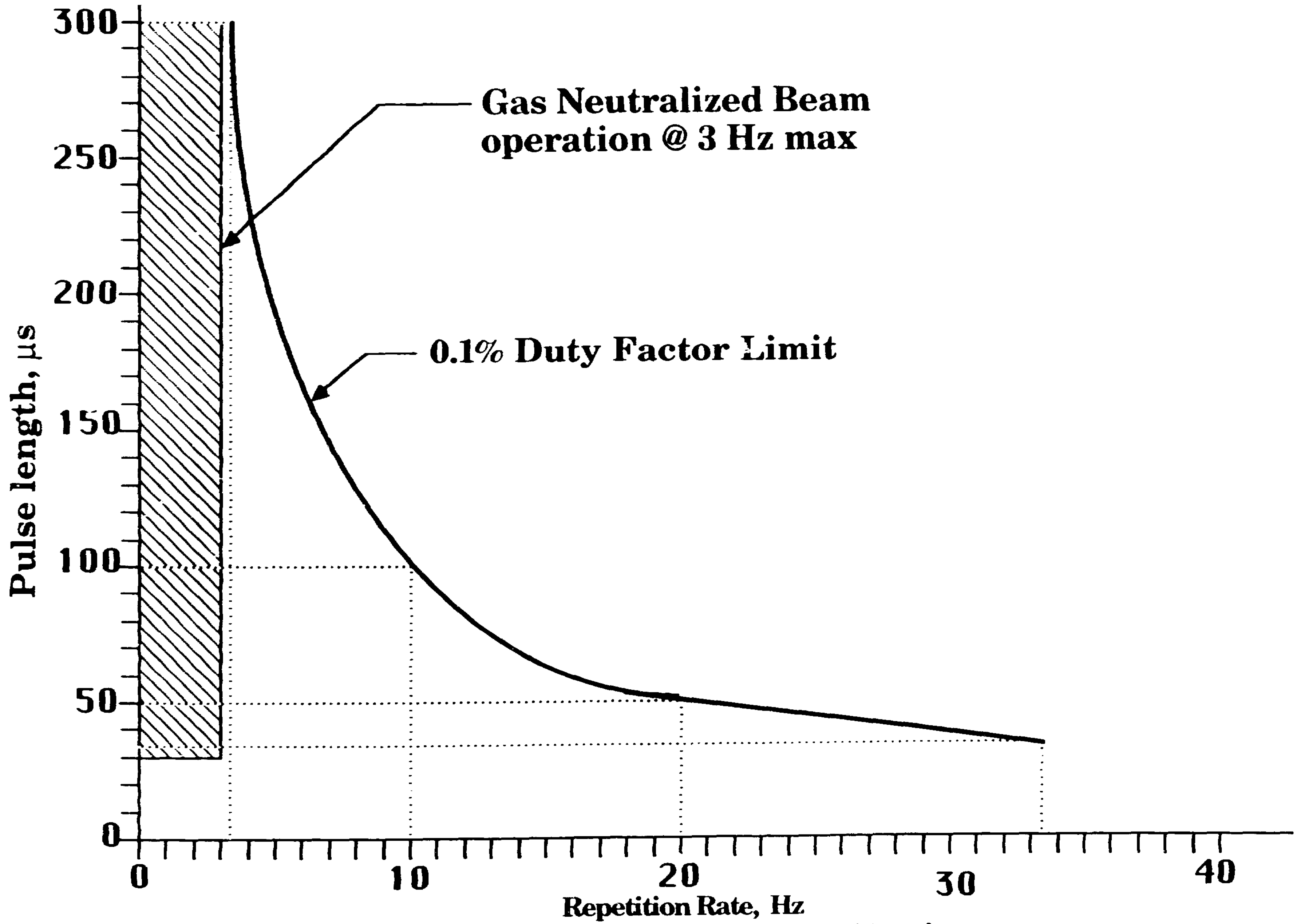
The accelerator beam vault to provide radiation shielding is located within the high bay area. Precast, high-density concrete blocks are used for the beam vault walls. Precast concrete beams form the roof with the first layer high-density concrete and the remaining layers normal-density concrete. A ten-ton crane is available for use in the high bay and a two-ton crane is located within the beam vault. RF power is located outside the beam vault in the low bay. Electronic equipment racks line both sides of the beam vault. Trenches are provided for some of the cooling-water pipe runs, although a raised floor is required in certain areas. Ventilation in the beam vault provides once-through air at the proper temperature and humidity. Special air handling reduces radiation transmission to external areas.



GTA-1 FACILITY CROSS SECTION

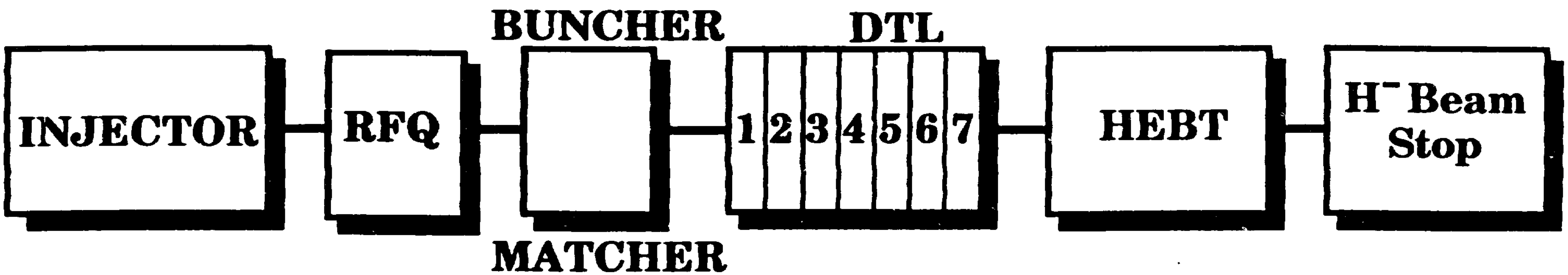
GTA PHASE 1 OPERATING REGION

The system is designed to operate with pulse lengths in the range of 30 to 300 μs. The shorter pulse lengths will be used to minimize activation and damage during initial accelerator tuning. The gas neutralizer repetition rate is limited to 3 Hz which will be the maximum repetition rate for the neutral beam. All other components are designed for higher repetition rates, at the shorter pulse lengths, to assist in data taking. The maximum accelerator repetition rate may be determined by the control system and will be established after all of the control requirements have been analyzed. In any case, the repetition rate will not be continuously variable but have a number of discrete values established by experimentally obtained stable operating points.



GTA Phase 1 Operating Region

GTA Phase 1
Accelerator System



GTA PHASE 1 INJECTOR REQUIREMENTS

Ion Source	
Ion	H^-
Ion Source Type	Dudnikov (small angle source)
Pulse Width (variable)	30-300 μs (operating), 2 ms (design)
Duty Factor	0.1% (operating), 5% (design)
Repetition Rate	Consistant with 0.1% DF (single pulse capability required)
Output Current	150 mA (nominal)
Current Variability	5% rms
LEBT	
Output Energy	100 keV (nominal)
Output Current (H^-)	>120 mA
Normalized RMS Output Beam Emittance (at 100 keV)	0.017π cm-mrad (rms normalized) (at full current)
Focus System	Permanent magnet
Beam Space-Charge Neutralization	Xenon Residual Gas
Beam Matching to RFQ	Maximum angle 41 mrad Beam waist radius 1.0 mm
Injector Total Length	<1.1 m

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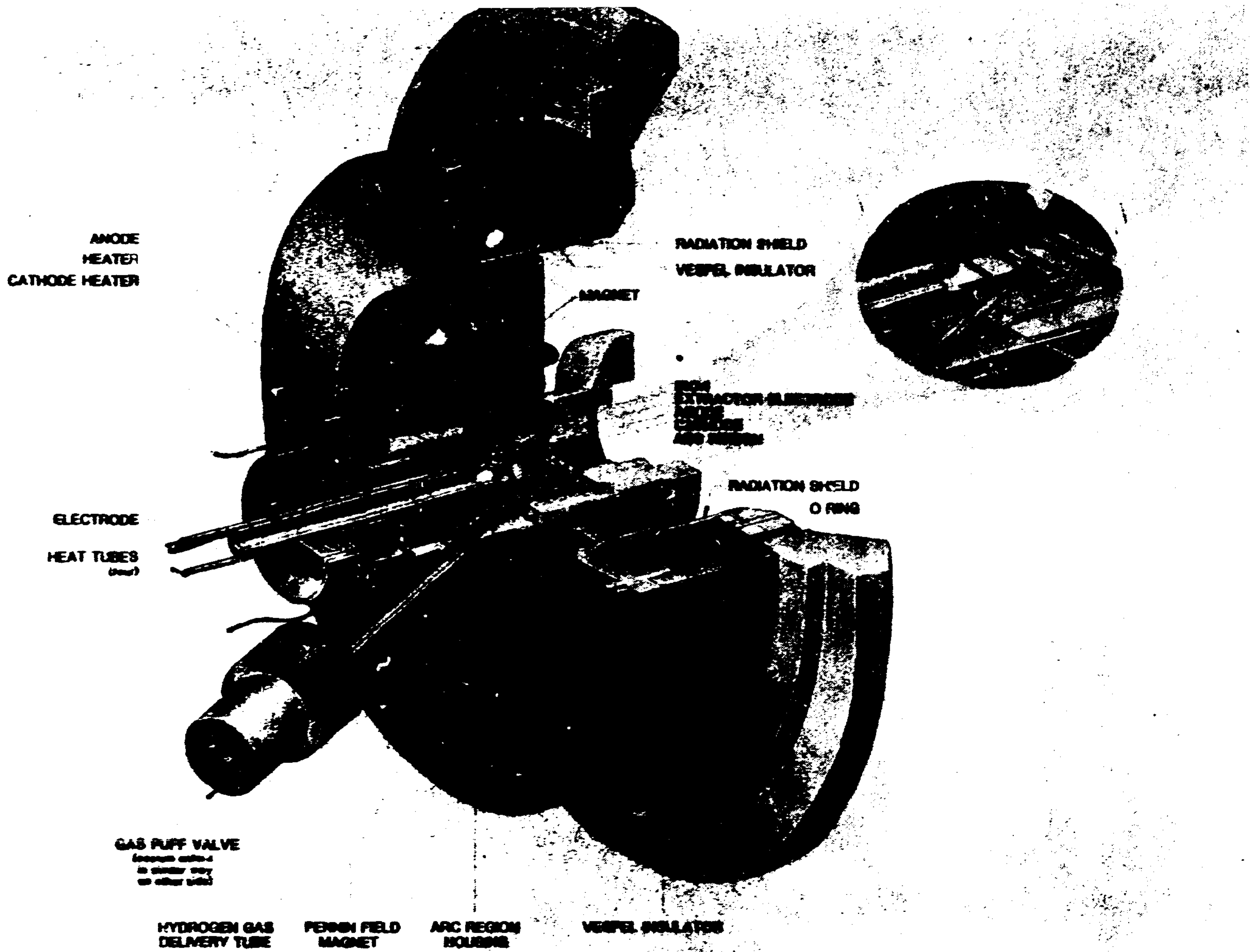
INJECTOR BASELINE DESIGN

Ion Source	Dudnikov small angle source (based on ATS and Bear)
Arc Chamber	Cartridge type
Cesium Production	Independently controllable oven
Hydrogen Flow Control	Piezoelectric Valve
LEBT Lenses	SmCo permanent magnet quadrupole
Neutralization	Xe (10^{-5} torr)
High Voltage	Pulsed 100 kV
Control	Automatic computer start up and operation



H$^-$ SOURCE ION
CANISTER PACKAGE
GTA-1

GTA PHASE 1 RADIO-FREQUENCY QUADRUPOLE REQUIREMENTS

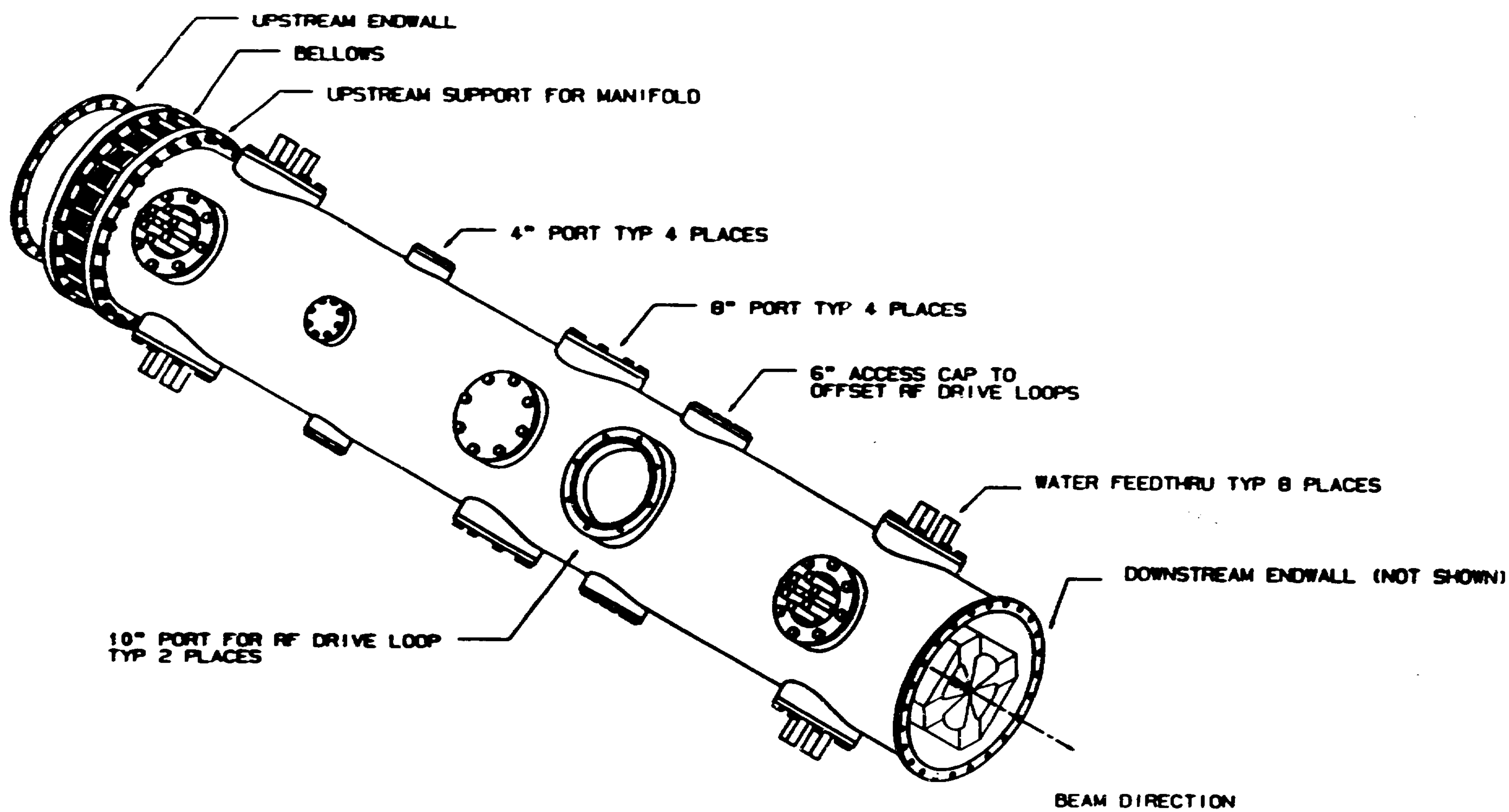
Operating Frequency	425.000 ±0.010 MHz
Operating Frequency Stability	± 10 kHz
Operating Frequency Tuning Range	± 20 kHz
Injection Energy	100 keV (nominal)
Output Energy	2.07 MeV
Input Current	120 mA
Output Current	>106 mA
Duty Factor	0.1% (operating), 5% (design)
Normalized RMS Output Beam Emittance	<0.02 π cm-mrad (nominal)
Total Length	<2.65 Meters
RF Drive	Loop Coupled, two each 250 kW
RF Field Dipole Content	<5%
RF Field Flatness (longitudinal)	<5%
Maximum Surface Electric Field	≤36 MV/m (1.8 x Kilpatrick)
Beam Matching	Buncher

RFQ BASELINE DESIGN

- Solid copper tips explosively clad to copper-plated steel vanes
- Copper liner on skirts
- Steel vacuum tanks
- RFQ frequency tuning accomplished by controlling water temperature
- Vane coupling rings provide RF field homogeneity
- Two each 250 kW RF power drive loops

GTA PHASE 1

RADIO-FREQUENCY QUADRUPOLE (RFQ)



GTA PHASE 1 BUNCHER/MATCHER REQUIREMENTS

Operating Frequency	425 MHz (nominal)
Duty Factor	0.1% (operating), 5% (design)
Maximum Gradient	E_oT = 3 MV/m
Maximum Surface Field	$\leq$1.5 x Kilpatrick
Beam Matching	Ramped Gradient DTL (AT-1 86-19; Mills, Wangler, & Crandell, January 28, 1986)

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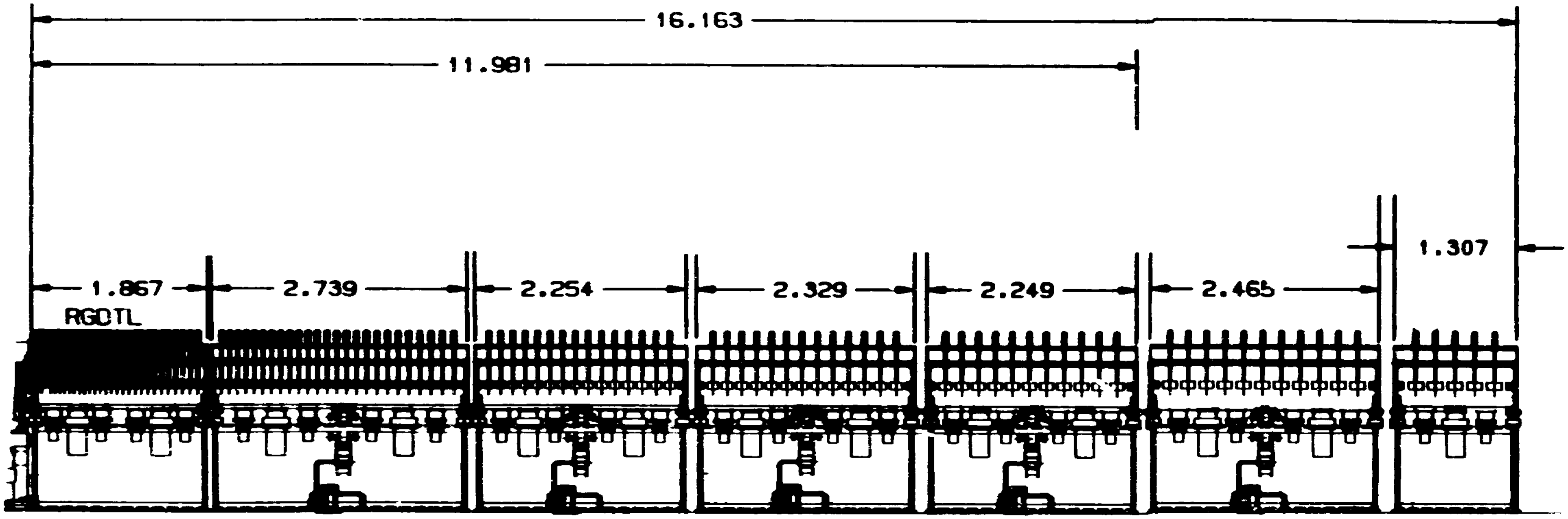
GTA PHASE 1 DRIFT-TUBE LINAC (DTL) REQUIREMENTS

Operating Frequency	425 ± 0.10 MHZ
Input Energy	2.07 MeV (nominal)
Output Energy	50.0 MeV (nominal)
Output Momentum Spread ($\Delta P/p$)	<0.001 (rms)
Output Beam Current	100 mA (nominal)
Beam Loss at Nominal Current	<1%
Duty Factor	0.1% (operation), 5% (design)
Normalized rms Output Beam Emittance	0.02 π cm-mrad (nominal)
Maximum Surface Field	$\leq$1.5 Kilpatrick
Average Accelerating Gradient	<5.0 MV/m
RF Drive	Loop coupled, two and four drives/tank, <2 MW/tank
Length To Simulated Hinge Point	<12 Meters (nominal)

DTL BASELINE DESIGN

1. Split permanent magnet (Nd_2 Fe_{14} B) drift tubes with integral diagnostics
2. Soft point socketed, single stem quadrupoles
3. Copper-plated aluminum tanks reduce RF dissipation losses and minimize neutron-induced activation
4. Seven tanks, 109 drift tubes
5. Gradients
    a) RGDTL - 2-4.4 MV/m
    b) DTL - 4.4-5 MV/m
6. 5% duty factor design, 0.1% operation
7. Loop coupled, 500 kW RF drives, four drive ports/tank, two drive ports/tank for RGDTL and last tank
8. Rotary tuners and post couplers
9. Top loading girder/drift- tube assembly



GTA PHASE 1 DRIFT-TUBE LINAC (DTL)

GTA PHASE 1 BEAM MAGNETIC OPTICS REQUIREMENTS

Input Beam Assumptions (Output of DTL)

Energy	50 MeV
Momentum Spread	<±0.1%
Current	100 mA, H^- (nominal), 20 mA tune-up
Emittance	0.02 π cm-mrad, rms normalized
Beam Radius	<1.25 mm rms

Output Requirements

Beam Divergence (after steering)	≤25 μrad, rms (normalized)
Beam Steering Range	0 to 0.5° in one plane
Focusing Range	1 - 100 km
Beam Direction	180° from input direction
Output current (H^-)	100 mA nominal
Total Length	<TBD m

GTA PHASE 1 DETAIL BEAM MAGNETIC OPTICS REQUIREMENTS

1.0 Matching Section

Must be able to match to 180° bend or HEBT and H^- beamstop as required

2.0 180° Achromatic Bend System

Type	Achromatic
Imaging	1:1
Effective Bending Diameter (centerline to centerline)	<3.2 m

3.0 Momentum Compactor

Momentum Compaction	>3
Frequency	425 MHz
Current (H^-)	100 mA
Duty Factor	>0.1%

4.0 Beam Expanding Telescope — (10.0 m nominal length)

rms Divergence	<25 μrad (θ/2) rms
Focus Range	1 to 100 km

5.0 Steering Magnet

Steering Range	0 to 0.5° in one plane
Steering Accuracy	<10 μrad
Slew Rate	1 degree/s
Divergence	<25 μrad (θ/2) rms

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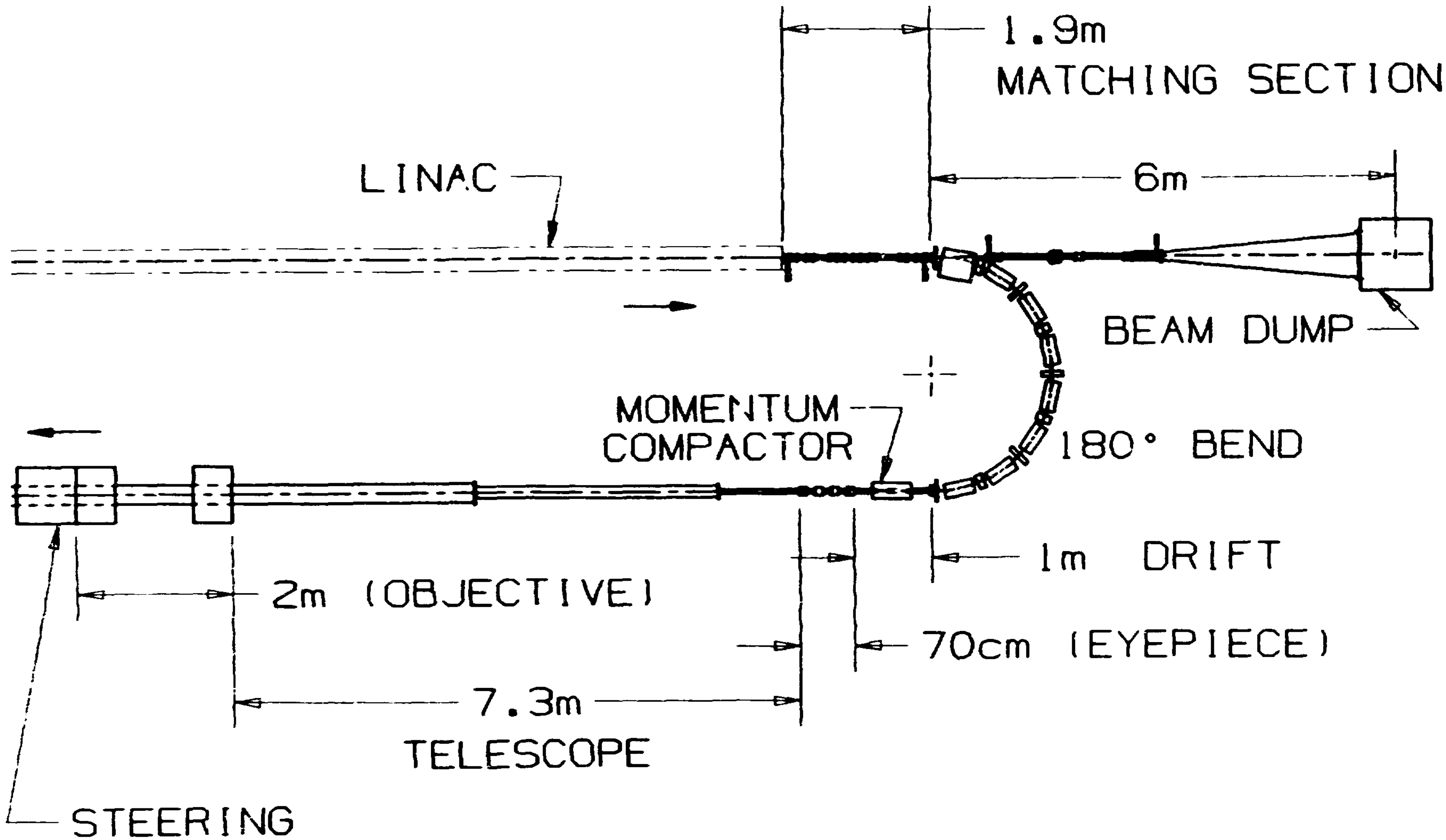
BEAM MAGNETIC OPTICS BASELINE DESIGN

- o Matching Section
  - length <2 m
  - four electromagnet quadrupoles
- o 180° Bend
  - first element is electromagnet to switch beam from HEBT to 180° bend
  - seven permanent magnet dipoles and nine permanent magnet quadrupoles
  - neodymium-iron or samarium cobalt permanent magnets
  - periodic FODO system
  - 3 cm clear aperture
  - 1.5 m bend radius
- o Momentum Compactor
  - side coupled cavities
  - <50 cm length
  - <125 kW RF power total (1^{st}, 2^{nd}, and 3^{rd} harmonics)
- o Beam Expanding Telescope
  - length 10 m
  - expansion x25
  - permanent magnet quadrupole doublet eyepiece
  - permanent magnet quadrupole doublet objective
  - neodymium-iron or samarium cobalt permanent magnets
  - electromagnet (Lambertson/printed circuit type) trim coil
- o Steering Magnet
  - electromagnet dipole(Lambertson/printed circuit type)
  - clear aperture 30 cm



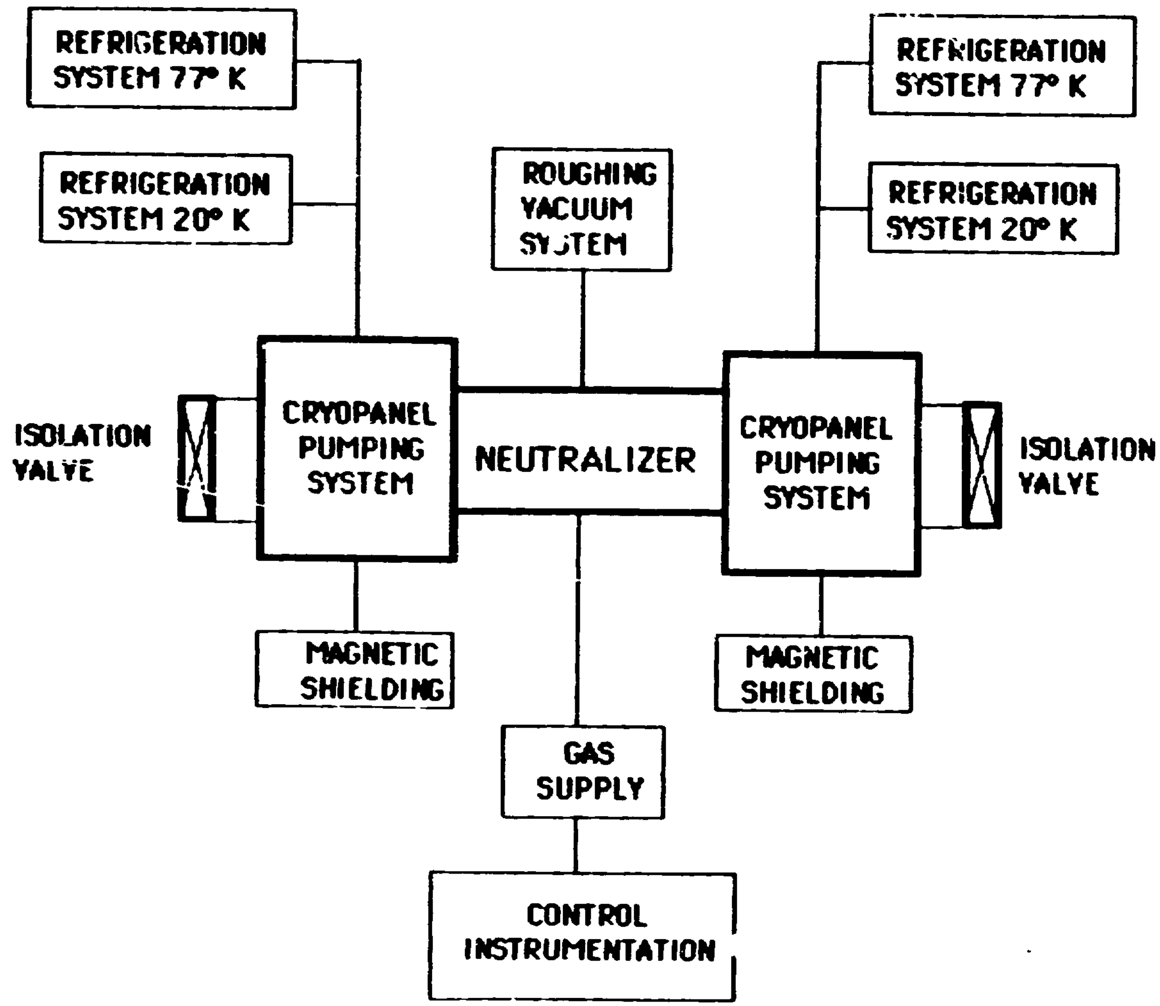
GTA PHASE 1
OUTPUT OPTICS LAYOUT

GTA PHASE 1 NEUTRALIZER PERFORMANCE REQUIREMENTS

Input Particle	H^-
Output Energy (H°)	50 MeV (nominal)
Input Beam Current (H^-)	100 mA
Neutralization Efficiency (H°/H^-)	>45%
Output Beam Divergence (H°)	$\leq$25 µrad ($\theta/2$) rms
Duty Factor	0.1%
Beam Pulse Width (variable)	30 to 300 µs
Pulse Repetition Rate	$\leq$3 Hz
Beam Steering	0 to 0.5°, one plane
Output Beam Diameter	5.0 cm rms

GAS NEUTRALIZER BASELINE DESIGN

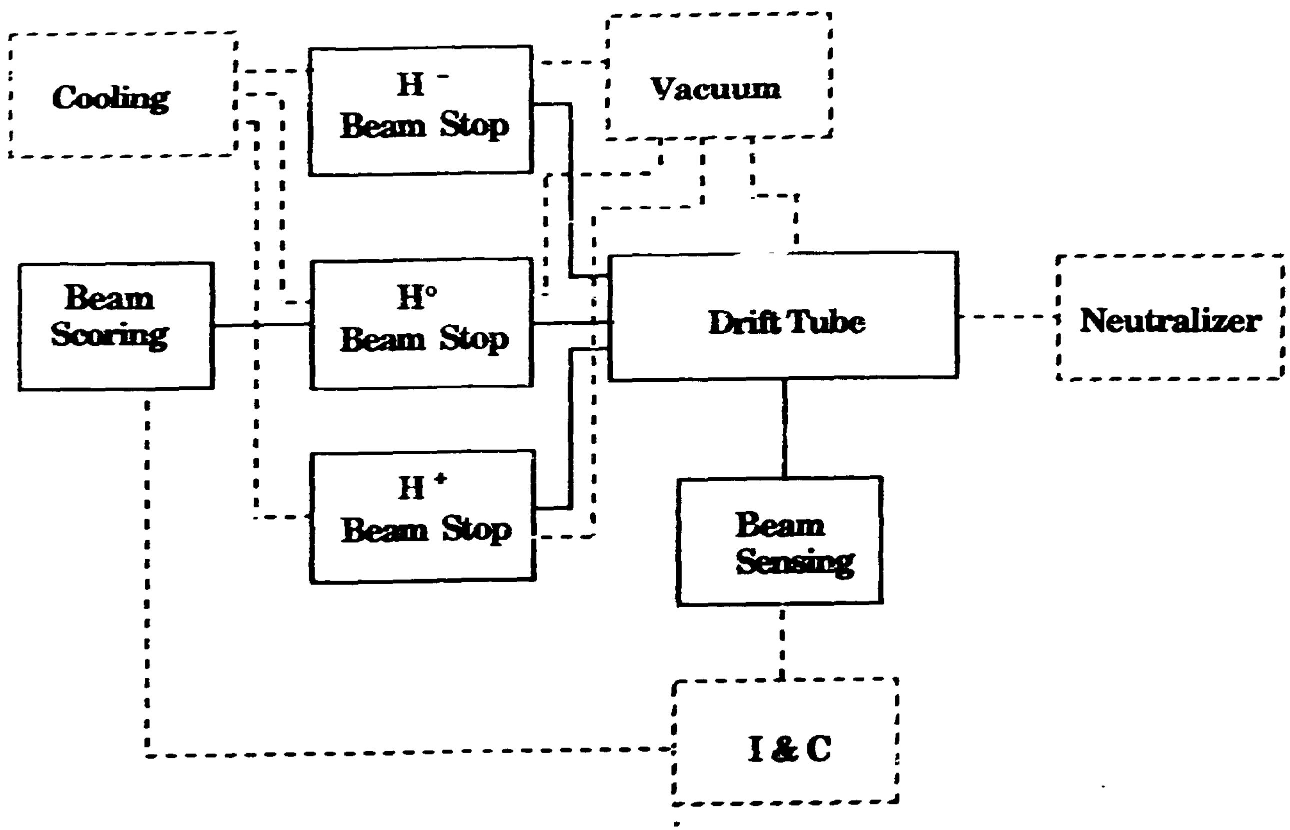
- Argon gas medium
- Total length <6 m
- Gas flow coaxial with beam path
- Cryogenic panels at 20° K helium temperature to remove injected neutralization gas
- Magnetic shielding will be Mu metal
- $<10^{-5}$ torr background pressure in magnetic optics volume due to neutralizer gas
- $<10^{-6}$ torr background pressure at beam sensing location due to neutralizer gas
- Provision for foil neutralizer



GTA PHASE 1 GAS NEUTRALIZER

GTA PHASE 1 BEAM SENSING PERFORMANCE REQUIREMENTS

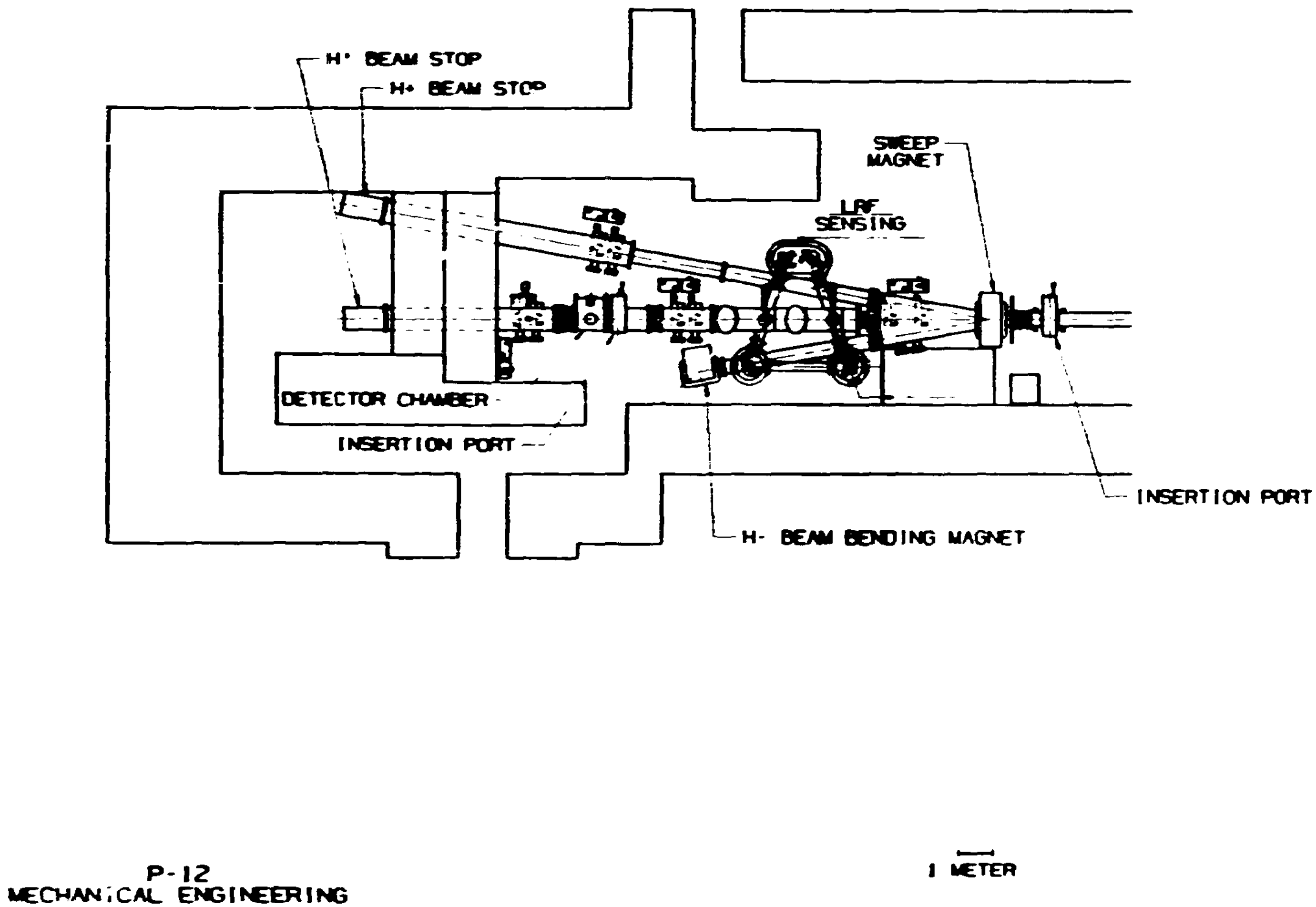
Beam Sensing	
Measure H° beam centroid direction	±10 μrad
Beam Measurements	TBD
Beam Intensity	
Beam Profile (intensity vs x&y)	
Beam Energy Spectrum	
Beam Flux	
Beam Centroid	
Temporal Resolution	
Beamstops	
Particles	H°, H^{+}, H^{-}
Input Beam Energy	50 MeV
Input Beam Current (H°)	50 mA (nominal)



Beam Sensing Subsystem
Functional Relationship and Interfaces

BEAM SENSING BASELINE DESIGN

- o Beam Sensing
  - interceptive beam diagnostics
    - pinholes with fluorescent screen
  - non-interceptive beam diagnostics
    - laser resonant fluorescence
  - other techniques are being evaluated
- o H^0, H^-, H^+ Beamstops
  - graphite laminated to a cooled copper back plate
- o Beam Scoring
  - TBD

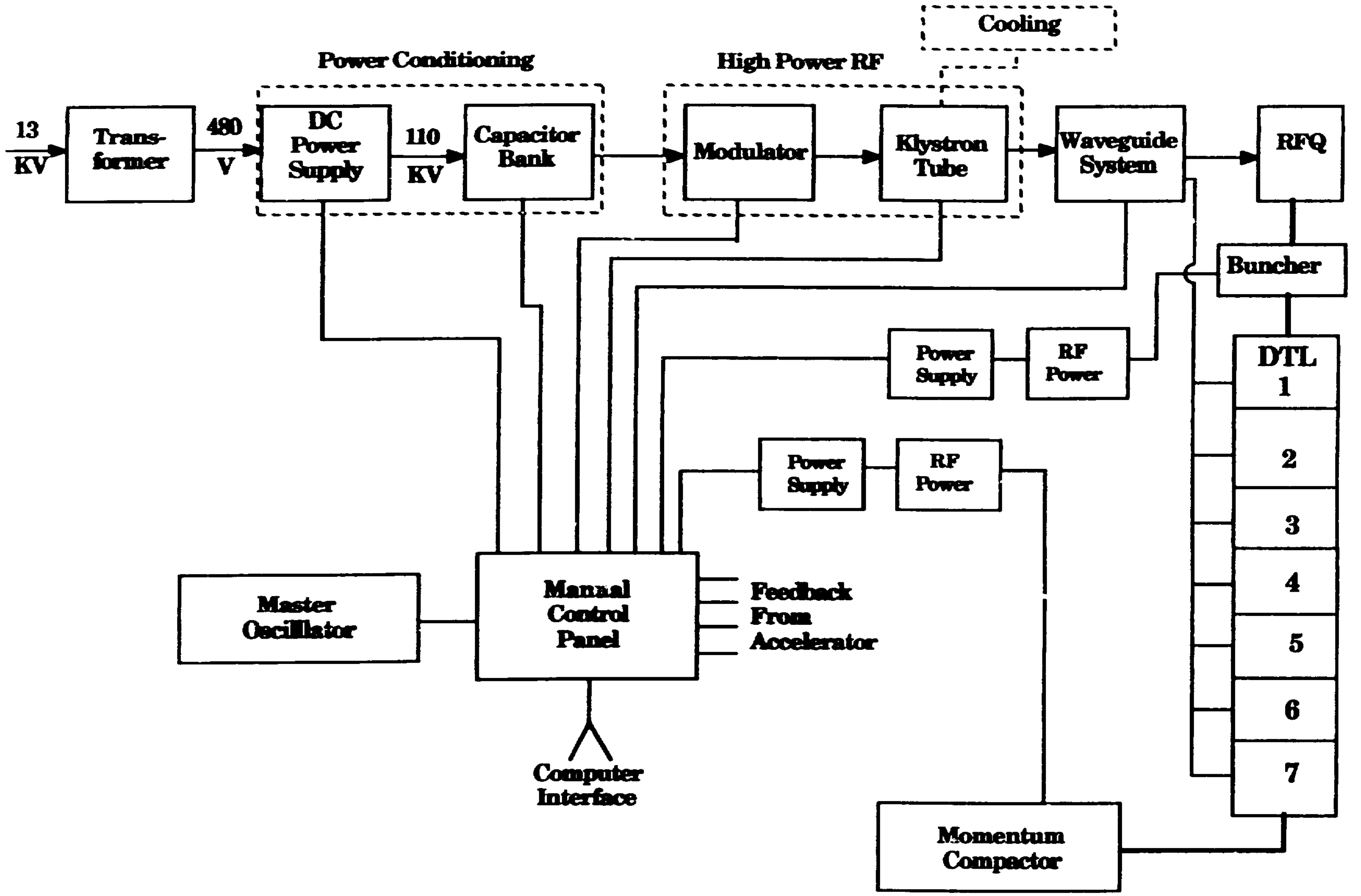


GTA PHASE 1 BEAM SENSING LAYOUT

GTA PHASE 1 RF SYSTEM PERFORMANCE REQUIREMENTS

Frequency	425 MHz
Bandwidth (1.0 dB Points)	±2.5 MHz
RF Power Required (peak)	MW
RFQ	0.506
Buncher	0.050
DTL 1 (RGDTL)	0.851
DTL 2	1.726
DTL 3	1.686
DTL 4	1.705
DTL 5	1.632
DTL 6	1.610
DTL 7	0.848
Momentum Compactor	0.125
Total	10.739 (no margin for overdrive)
Maximum beam current Fluctuation Accommodation	5%
Pulse Length (variable)	30-350 μs
Repetition Rate	Compatible with 0.1% DF
Duty Factor	0.1% (operating) ***
Amplitude Control	±0.5%
Phase Control	±0.5°
Load Reflected Power	Mismatches at start/end of pulse
Tube Type *	Klystron
Tube Output Connector	WR 2100 waveguide
Accelerator Structure Input Connector	6-1/8" coaxial line, loop driven
Power Level per Drive Loop **	500 kW (nominal)
Controls	Compatible with computer control

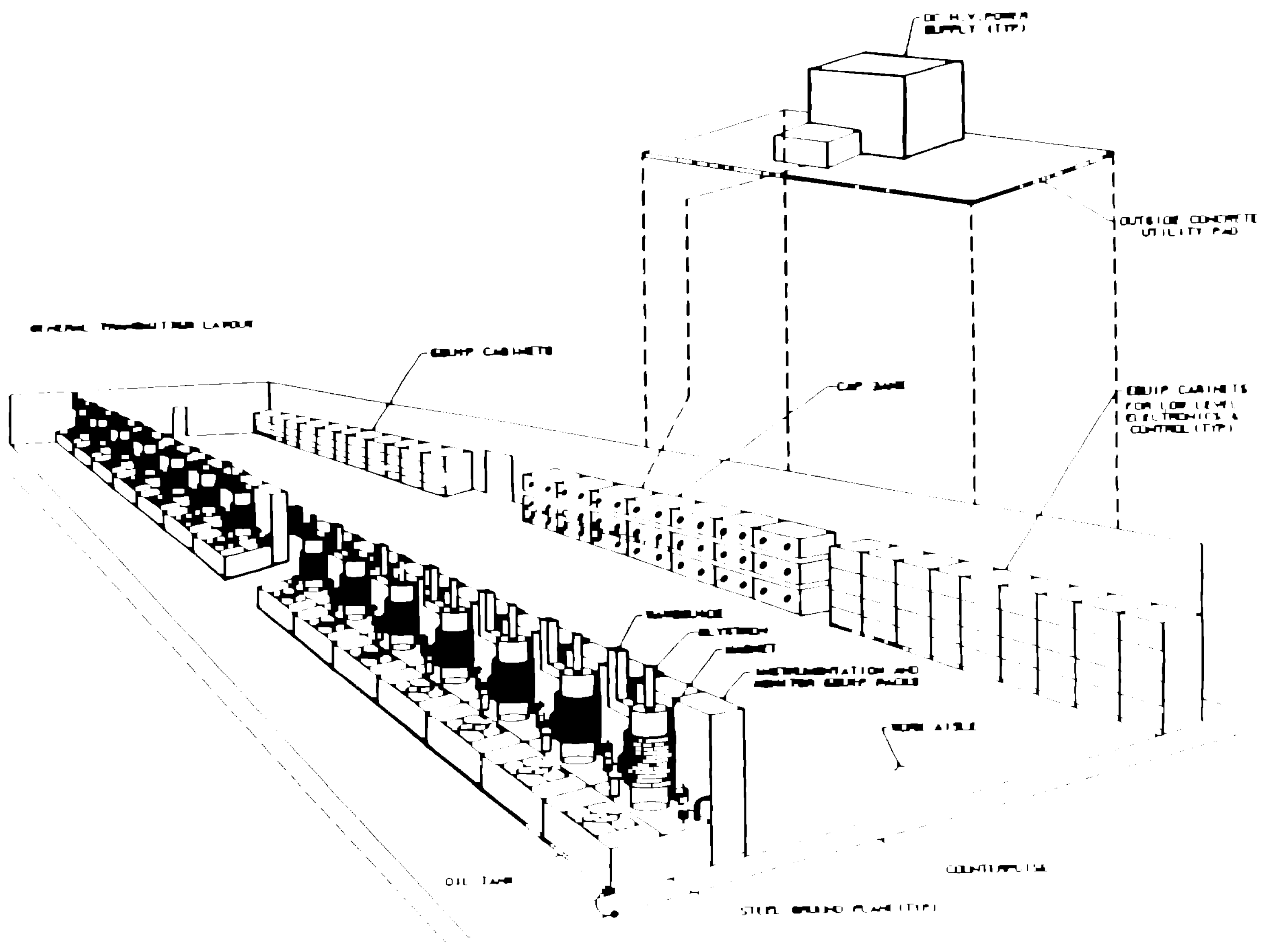
* Provision will be made to test 500 kW solid state RF units.
** One klystron drives two ports.
*** Provisions for reconfiguring RF system to drive one DTL tank at 5% duty factor.



GTA Phase 1 RF Power System

RF POWER BASELINE DESIGN

- Thirteen each 1.25 MW klystrons
- Thirteen each modulators with individul power conditioning
- WR 2100 waveguide klystron interface
- WR 1800 waveguide or 4 1/8 ID "flexible" coaxial air lines
- Single 120 kV dc power supply
- Directional couplers
- Isolators
- Phase shifters
- Transition to 6-1/8" coupling loop flange at accelerator



CONFIGURATION

Control System Requirements

- Provide independent supervisory control of each subsystem during commissioning
- Support automatic accelerator startup, operation, and shutdown
- Acquire, store, analyze, and display data and status information on any part of the accelerator from a central control station
- Respond to fault condition with fault logging and recovery procedures
- Provide a prototype environment for the development of space control system architecture, algorithms, data rates, and operator interface

GTA PHASE 1 ESTIMATED NUMBERS OF CONTROL SYSTEM INPUT/OUTPUT SIGNALS

Injector	150
RF Power	1200
Neutralizer	80
Cooling and Vacuum	1800
Beam Diagnostics	800
Beam Optics	780
Total	4810

Control System Baseline Design

Distributed Processing System Modules: The Control System is implemented using distributed processing to meet the processing requirements of GTA. With distributed processing more modules can be applied to the solution without major changes to the control software. These processing modules include a high performance 68020 CPU which supports 32 bit data and addressing, a IEEE-1014 VME Bus selected for speed, and a silicon software operating system which provides rapid task switching and interprocessor communication. 'C' is the development language being used.

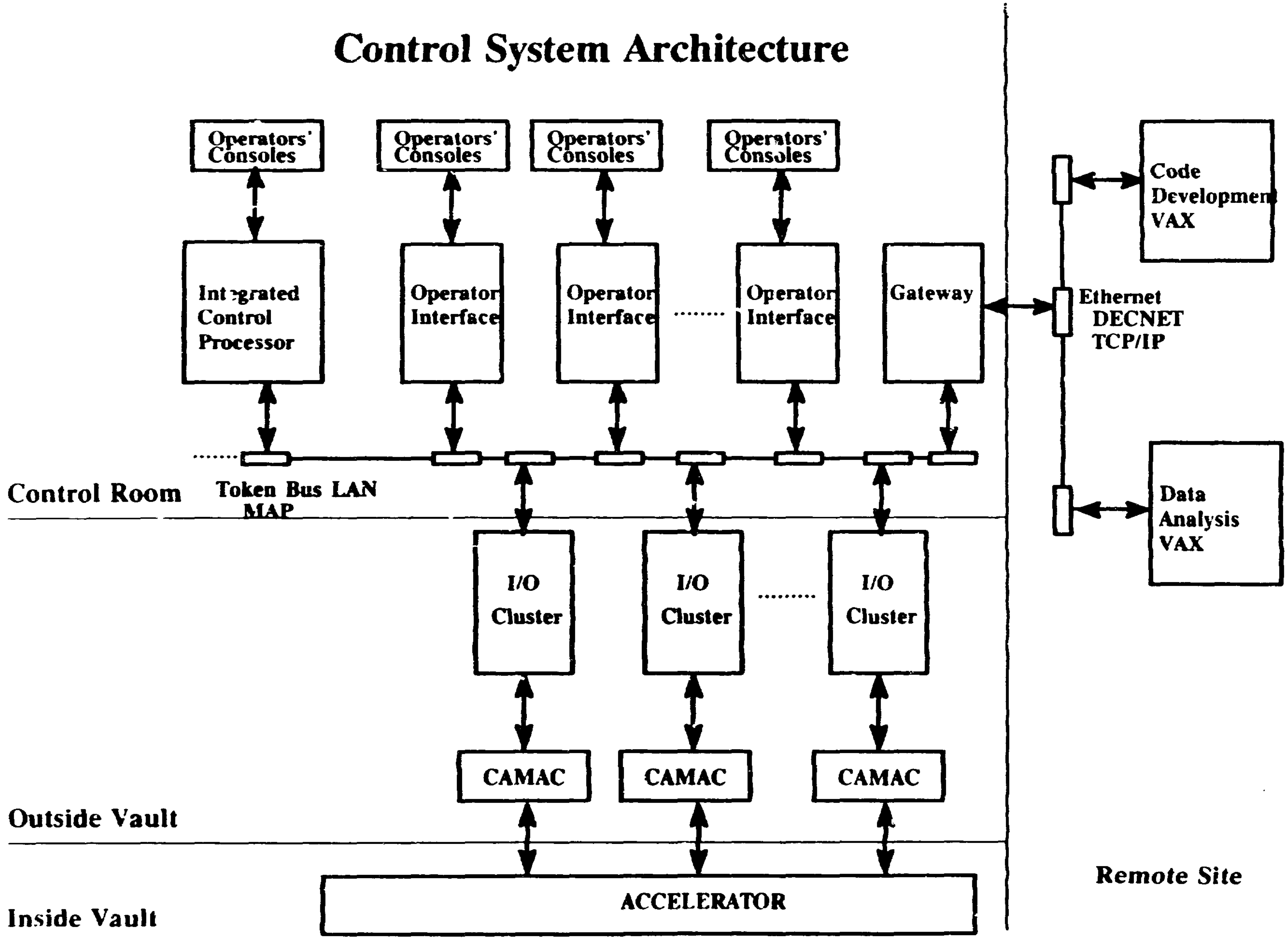
Token Bus Network: The IEEE-802.4 Token Bus Network is used as it guarantees access to the bus. The Token Bus Network is 10 Mbps. The token bus is limited to 256 nodes. Tests indicate that GTA control system will require less than 10% of the network bandwidth.

CAMAC Signal Conversion: The IEEE-583 CAMAC interface equipment is used since it supports most of the signal conversion requirements of GTA. Standard CAMAC modules are produced by many manufacturers.

VAX Data Analysis Support: Data Analysis is supported on a VAX as existing accelerator codes are running on VAX based systems.

Control System Baseline Design

- Distributed Control System Modules featuring:
  - VME Bus
  - 68020 CPU
  - Silicon Software Real-Time Operating System
  - 'C' Programming Language
- Token Bus Network Connecting Control System Modules
- CAMAC Interface Equipment
- VAX Based Data Analysis Machines



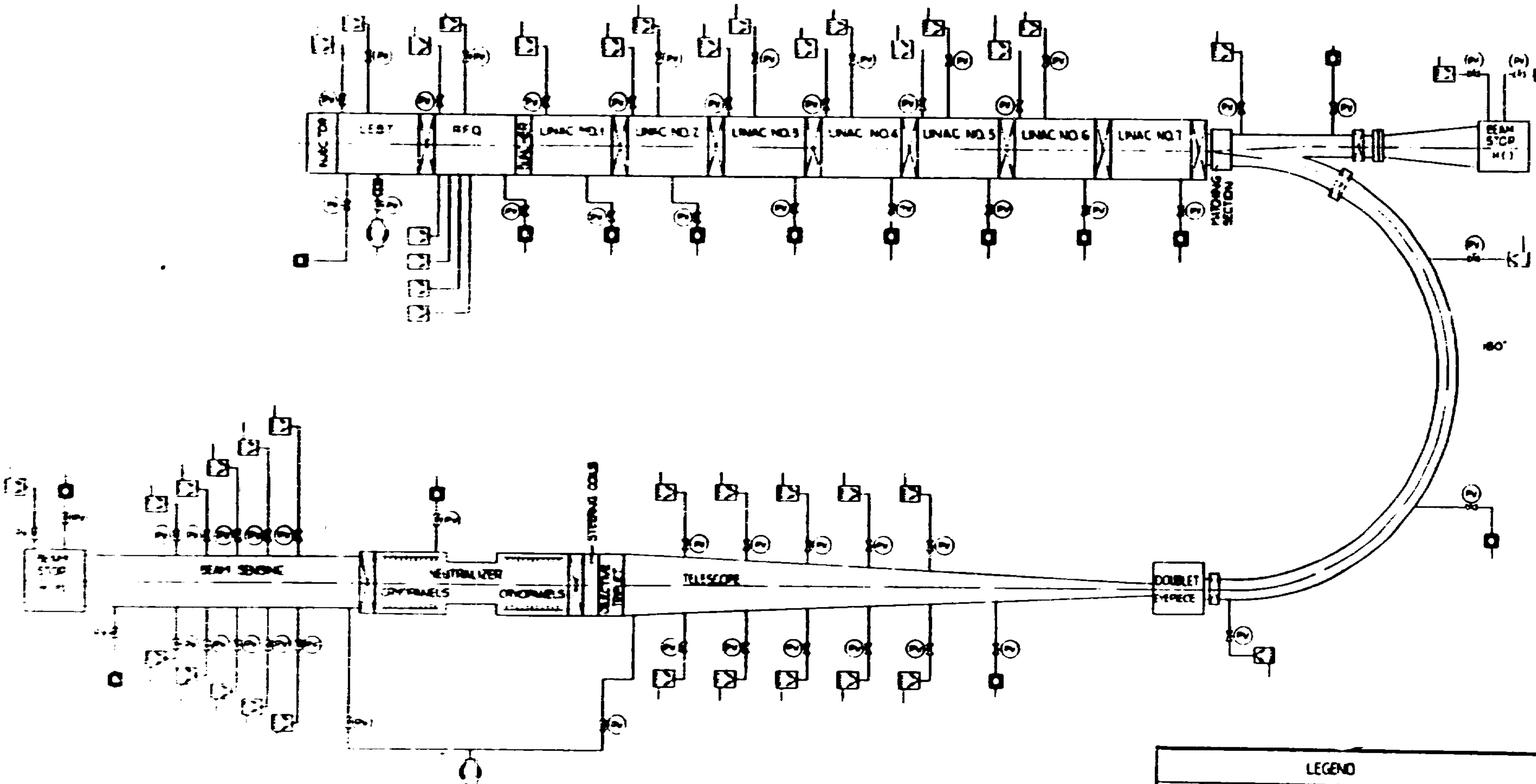
Control System Architecture
Operators' Consoles
Operators' Consoles
Operators' Consoles
Operators' Consoles
Integrated Control Processor
Operator Interface
Operator Interface
Operator Interface
Gateway
Code Development VAX
Ethernet
DECNET
TCP/IP
Data Analysis VAX
Control Room
Token Bus LAN
MAP
I/O Cluster
I/O Cluster
I/O Cluster
CAMAC
CAMAC
CAMAC
Outside Vault
Remote Site
ACCELERATOR
Inside Vault

VACUUM SYSTEM REQUIREMENTS

- Nominally maintain 10^{-6} torr in all sections of machine
- Pump high gas loads of H_2 and Argon
- Provide reliable system with ability to quickly locate leaks

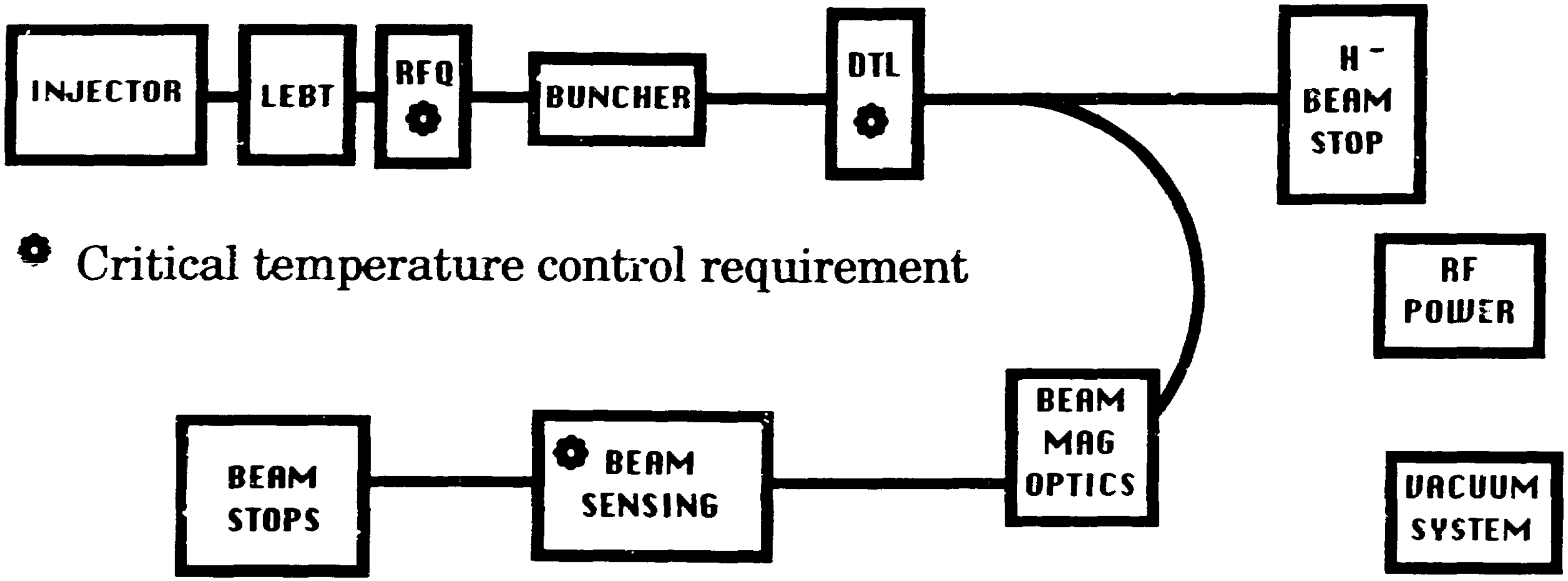
VACUUM SYSTEM BASELINE DESIGN

- o High vacuum cryogenic (cryoadsorption) pumps to handle gas load
- o Turbomolecular pumps for quick pump-down of the system for leak checking
- o Mechanical roughing pumps to achieve cross-over pressure for the turbomolecular pumps
- o High vacuum gate valves isolate components to facilitate leak checking, maintenance and cryopump regeneration
- o Installed residual gas analyzers to quickly indicate vacuum leak or outgassing problem



LEGEND					
SYMBOL	NAME	CAPACITY	PWR REQ'D	SIZE	ETC
	CRYOGENIC PUMP				
	ROTARY BLR PUMP				
	MECHANICAL PUMP				
	TURBOMOL PUMP				
(PV)	PRESSURE CONT VALVE				

GTA Phase 1 Vacuum System



11 components of GTA-1 have been identified that require cooling.

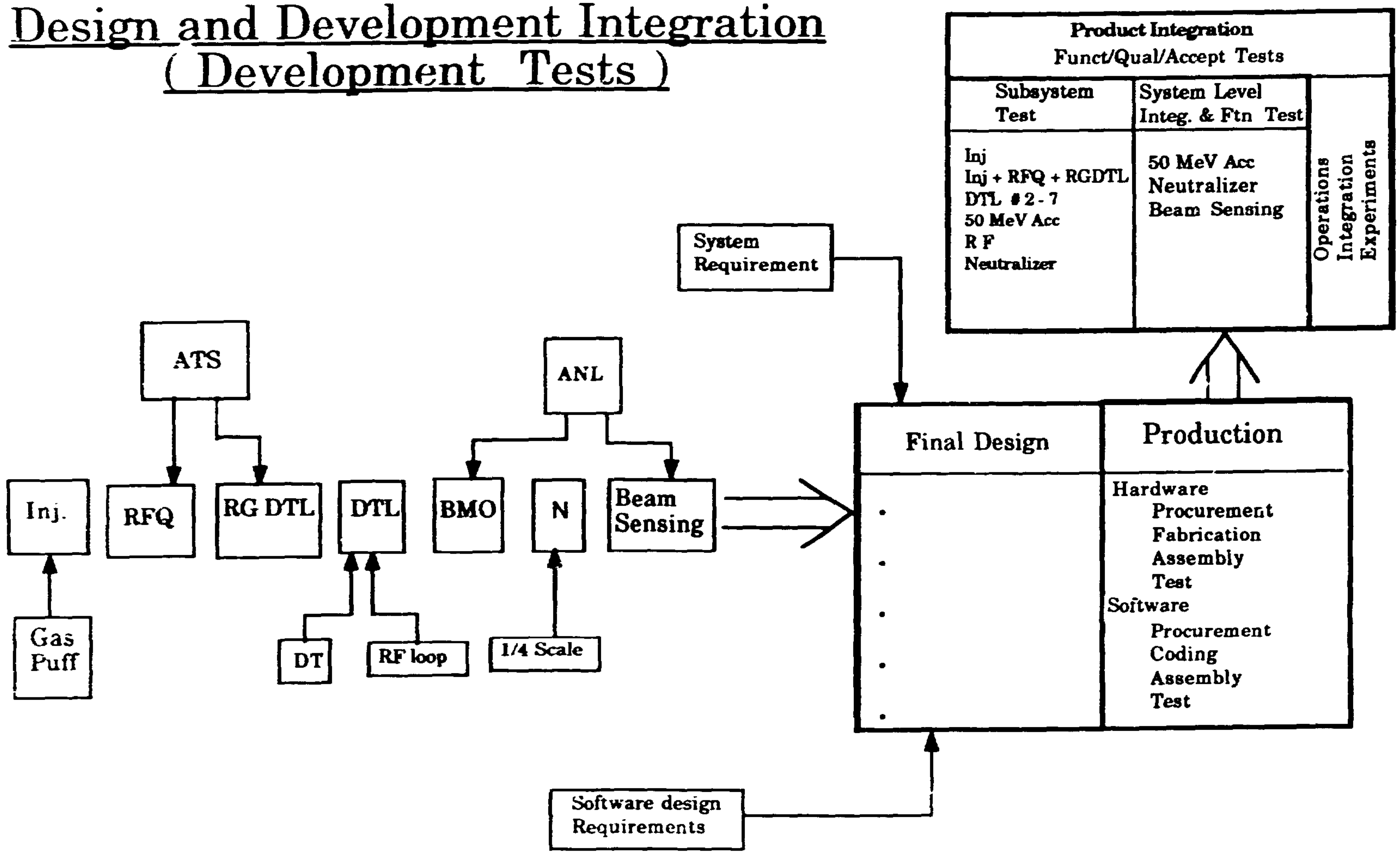
GTA Phase 1

Cooling System Requirements

COOLING SYSTEM BASELINE DESIGN

- Deionized water for heat removal and transport
- Mixing valves and controls for precision temperature regulation of RFQ, DTL, and beam sensing
- Isolated cooling loops for beam stops to avoid radioactive water exchange
- Use existing cooling tower with additional chillers and heaters for critical loops
- Modular design and prefabrication
- Vibration isolation and dampening via flexible hoses and accumulators

Design and Development Integration
(Development Tests)



Systems Integration and Tests

GTA PHASE 1 OPERATIONAL TESTING

This testing involves the entire GTA Phase 1 NPB system. The test objectives for the GTA Phase 1 operational testing are listed below:

- Demonstrate beam operation at full current and energy
- Measure the following beam properties:

Energy	H^- and H° beams
Current	H^- and H° beams
Emittance	H^- beam
Divergence	H° beam
Profile	H° beam

  Steering Characteristics

  Neutralization Efficiency (H°/H^-) and uniformity
- Demonstrate integrated operation of the end-to-end NPB system under automatic control to simulate the functions required by ISE-1.
- Determine actual thermal control requirements.
- Confirm alignment requirements and proceedures.
- Determine gas load into vacuum
- Sense direction of neutralized beam centroid to 10 μrad accuracy and measure the focus (at 3σ) to an accuracy of 1 μrad.
- Demonstrate variable focus over a range of 100:1 and beam deflection of 0.5° in one plane.

GTA PHASE 1 SEQUENTIAL TURN-ON AND CHECK-OUT

ION SOURCE

Test Objectives: Measure output emittance, >135 mA current, reliability, reproducibility, understanding and control effects of source parameters.

Diagnostics: Faraday cup*,1, electric sweep scanner*,1

Beam Control: Source parameters, x, y positioning without breaking vacuum.

COLUMN AND LEBT

Test Objectives: Determine match to RFQ, emittance, adequate current (>120 mA if matched), reproducibility, reliability.

Diagnostics: Faraday cup*,1, toroidal current monitor*,1,2, electric sweep monitor*,1 (good to 100 mA, 2 mm radius, 1 ms, CU)

Beam Control: Source parameters, encoded-movable PMQs (to obtain good match), two steering magnets (to give $x, y, x^1, y^1 = 0$), variable aperture for adjusting beam current.

Simulations: Desired RFQ matched conditions from TRACE, LEBT match of source to RFQ.

* Diagnostic for turn on and subsequent module test

1 Capable of high current

2 Capable of high duty factor

CTA PHASE 1 SEQUENTIAL TURN-ON AND CHECK-OUT (cont.)

RFQ

Test Objectives: Test for output energy, emittance growth, transmission, voltage/power operating point, proper transverse and longitudinal emittance shape for DTL acceptance, calibrate stripline with beam, control resonant frequency, maintain current and emittance stability.

Diagnostics: Toroidal current monitor[*,1], striplines[*,1,2], slit and collector[1], LINDA[1,2], spectrometer.

Beam Control: Vane voltage amplitude control, resonant frequency control.

Simulations: Output emittance (what's expected, needed, also sets dimensions of emittance gear), effects of misaligned input beam.

BUNCHER

Test Objectives: Set phase and amplitude for correct longitudinal emittance for DTL, verify correct transverse emittance for DTL, verify and obtain low emittance growth.

Diagnostics: Slit and collector[1], LINDA[1,2], spectrometer[1].

Beam Control: Amplitude and phase control

Simulations: Expected and needed output emittance.

DTL

Test Objectives: Set phase and amplitude, obtain good transmission, verify output longitudinal and transverse emittance (high and low current) for subsequent DTL's, determine effects of steering, calibrate striplines, determine 2nd moments at matched conditions, optical profiles at match, determine acceptable levels in spill monitors.

Diagnostics: Spectrometer, LINDA[1,2], slit and collector, torroids[*,1,2] striplines[*,1,2], optical profile readouts[*,1,2], absorber-collector[*] (for phase scans), Δt[*,1,2], in intertank spacers. Adequate beam stops[1,2], wire scanners and/or harps[1].

Simulations: Output transverse and longitudinal emittance at end of each tank (for comparison with measurements and for setting dimensions of emittance gear.)

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BEAM MAGNETIC OPTICS

Test Objectives: Measure beam transport to H^- beamstop,
Measure output of 180° bend at low current (20 mA),
Measure beam divergence at output of telescope,
Measure beam steering 0-0.5° in one plane.

Diagnostics: Beam position monitors, current monitors (toroid), momentum detector (time of flight), profile monitors (interceptive and non-interceptive), loss monitors (TBD), emittance (laser neutralization, three wire scanners, pinhole imaging).

Beam Control: Electromagnet trimmers, adjustable permanent magnets, steering magnet.

NEUTRALIZER

Test Objectives: Measure gas flow field, gas density gradients, neutralization efficiency, beam density profile, neutralizer scattering.

Diagnostics: Pressure sensors, electron beam (gas density gradients), pinhole (charged particle and neutral beam).

Argonne

The Argonne facility provides timely experimental results for beam sensing, neutralizer and optics concepts at full energy but reduced current and pulse length (50 MeV, 1 mA H^-, 80 μs). The following will be investigated at Argonne:

- Thin foil neutralizers look promising to date but need to measure:
  - survivability
  - cross sections
  - angular divergence (scattering)
  - energy loss
- Backgrounds have been identified as a serious problem for beam sensing. Will investigate:
  - ionizing radiation
  - fluorescence
  - gas pressure and windows
  - shielding effectiveness against both prompt gammas and neutrons
- Measure beam characteristics:
  - spatial density profiles
  - temporal characteristics
  - foundation-transmitted vibration and movement
- Evaluate beam sensing techniques:
  - measure prototypic scintillator materials
  - characterize the shadow of a small diameter wire
  - test LRF and other non-interceptive methods
- Characterize 7.5 meter telescope containing a triplet objective lens
  - measure telescope performance with pinhole
  - evaluate steering magnet performance with expanded beam
- Evaluate micro-strip beam diagnostics performance with H^- beam

ARGONNE PHASE A AND PHASE B BEAM PARAMETERS

	Phase A	Phase B
Energy (MeV)	50	50
Current (mA)	1.0	2.5
Emittance (cm-mrad)	.02	.02
Pulse Length (μs)	80	300
Rep Rate (pps)	1-3	1-3
Duty Factor (%)	.02	.09
rms Size (cm)	~1	2.5
Beam Divergence (μrad)	large	25
Resolution (μrad)	-	10
Aperture (cm)	5	25

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GTA SUPPORTING PROGRAMS

ATS

The program will use ATS RF power for early demonstration of the accelerator system

- ATS provides klystron power (at up to 5% duty factor)
- Tuning, high power, and beam tests to be performed mid FY 87 for RFQ and ramped gradient DTL
- Develop automated injector control algorithms

GTA SUPPORTING PROGRAMS

BEAR

GTA-1 provides technology demonstration at increased performance levels:

	BEAR	GTA-1	FACTOR OF IMPROVEMENT
Energy (MeV)	1	50	x 50
Current (mA)	10	100	x 10
Divergence (mrad)	1000	25	x 40
Duty Factor (%)	0.025	0.1	x 4

GTA SUPPORTING PROGRAMS

The RF power development program provides early demonstration of advanced RF power concepts.

- Solid-state System
  - Westinghouse and Norden are under contract and working
  - Four 500 kW modules to be delivered to Los Alamos in 4Q/FY 87
  - Provisions are being made to test these units on the GTA Phase 1 accelerator
  - Interface is 6-1/8" coaxial line flange

III. A. ION INJECTOR

III. A. ION INJECTOR

III. A ION INJECTOR

1. Physics Criteria

The physics criteria which control the design of the GTA-1 Ion Injector have their basis in the accelerator test stand (ATS) developments. A Dudnikov source was chosen because, at the present time, no other H- ion sources can deliver the required current. The general design of the ion source is derived from the work on ATS and is based on the ion source designed for BEAR. The design of an ion injector cannot be independently broken down into three independent portions (source, acceleration column and beam transport) because the operation of the three components are interdependent.

PHYSICS CRITERIA

Type	Small Angle Cesiated (Dudnikov)
Accelerated Species	H-
Particle Energy	100kV
Beam Current	120 mA
Emittance	0.017 pi•cm•mrad (rms normalized)
Alpha Beta	α = 2.21, β = 0.072 mm/mrad
Penning Field	2200 gauss
Duty Factor	0.1%
Current Variation	20%, 100% Output Aperture

2. GTA-1 Ion Injec   nstraints

The engineering desig   he GTA-1 ion injector is further constrained by the mission of GTA-1, which is the support of ISE. In order to meet the mission objectives, the ion injector must be developed so that there is greater reliability. This constraint is particularly important in the design of the ion source.

The manner in which ion injectors have previously been designed has not made them easy to use in the space environment. The weight and volume of previous injectors has not been constrained and these represent the greatest difficulties to overcome. Considerable emphasis is being placed on reducing the weight, volume, and power consumption of the GTA-1 Ion Injector, but because of the third design constraint (automatic computer start up and operation), the GTA-1 injector will not meet all of the qualifying requirements.

A major contribution of the GTA-1 project will be the full implementation of automatic computer start up and operation of an accelerator, the greatest challenge of which may be implementing the required control system on the ion injector. To meet this challenge, the ion injector is being instrumented with more diagnostics than will probably be needed for a fully developed system in order to determine the parameters that will allow automatic computer control.

The method used in designing the GTA-1 Ion Injector is to follow the general design of the ATS injectors and gain as much general knowledge from the ATS experience as possible. Also, the ion injector being developed for the BEAR project will have to be flight qualified. Full advantage is being taken of the BEAR design of an ion source in the hope of meeting the eventual flight requirements and obtaining greater reliability in the ion source.

GTA-1 ION INJECTOR
DESIGN CONSTRAINTS

GOAL: REDUCE PHYSICS DEVELOPMENT TO ENGINEERING PRACTICE IN THE DESIGN OF ION INJECTORS

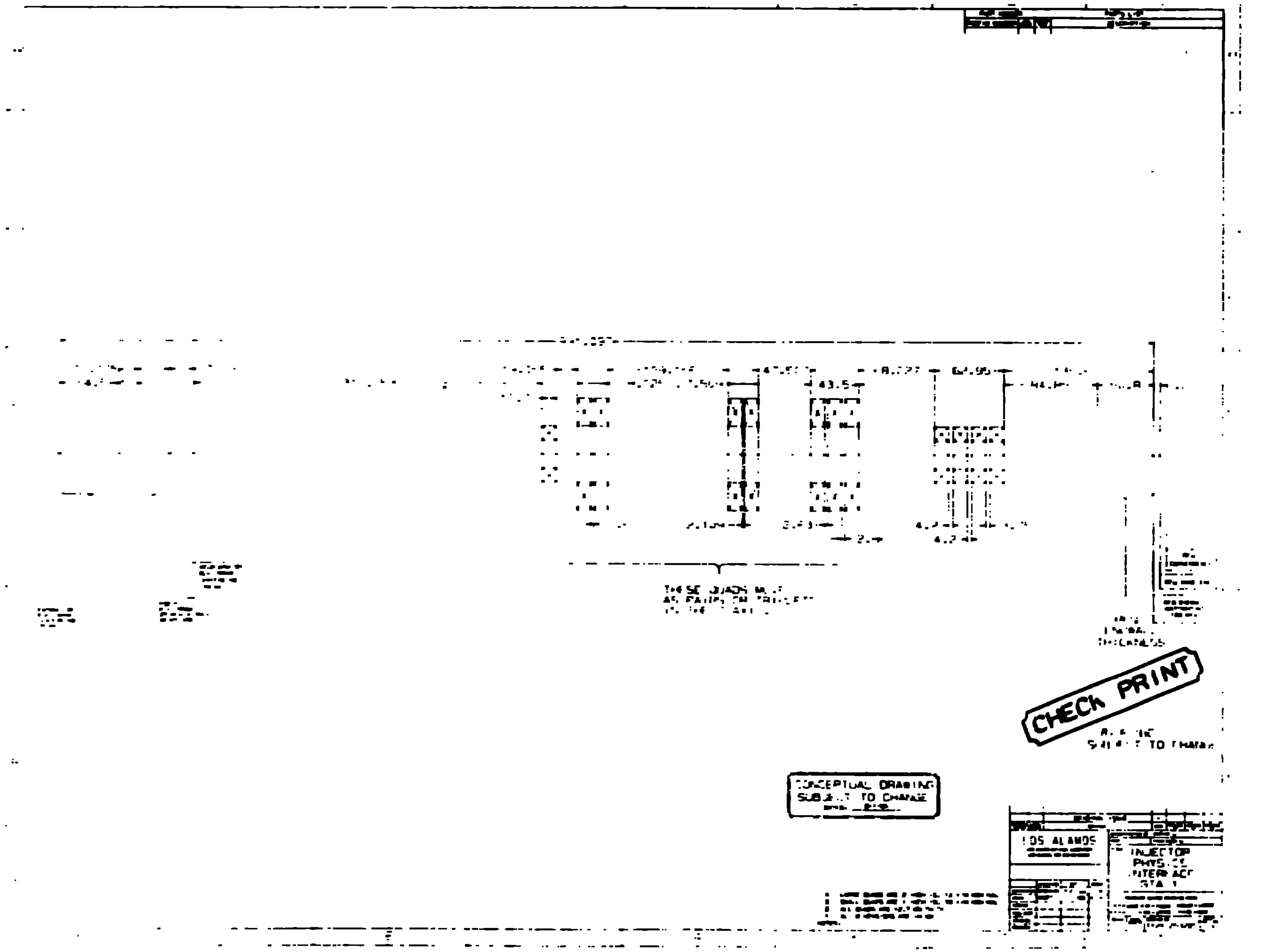
1. Improve Ion Source Reliability
2. Address Issue of Space Qualification
3. Provide Test Bed for Development of Automatic Control.

METHOD

1. Use ATS System as Design Basis
2. Use BEAR Design as a Guide.

3. GTA-1 Ion Injector Physics Footprint

The physics footprint refers to the physical layout of the various major components of the injector necessary to meet the interface requirement at the RFQ. The design of the GTA-1 RFQ has been changed from the ATS RFQ in order to achieve the acceleration conditions with the use of less power. This constraint has changed the design conditions of the GTA-1 Ion Injector to some degree and, in particular, the design of the low-energy beam transport (LEBT) has changed considerably. The LEBT will incorporate permanent-magnet (PM) quadrupole lenses of the same engineering design as the lenses used in ATS; however, the spatial position of those magnets has changed. The physics footprint includes the ion source as a point in space at which ions of the given emittance are available. We assume that the GTA-1 ion source will be able to meet those conditions.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THESE QUADS MUST
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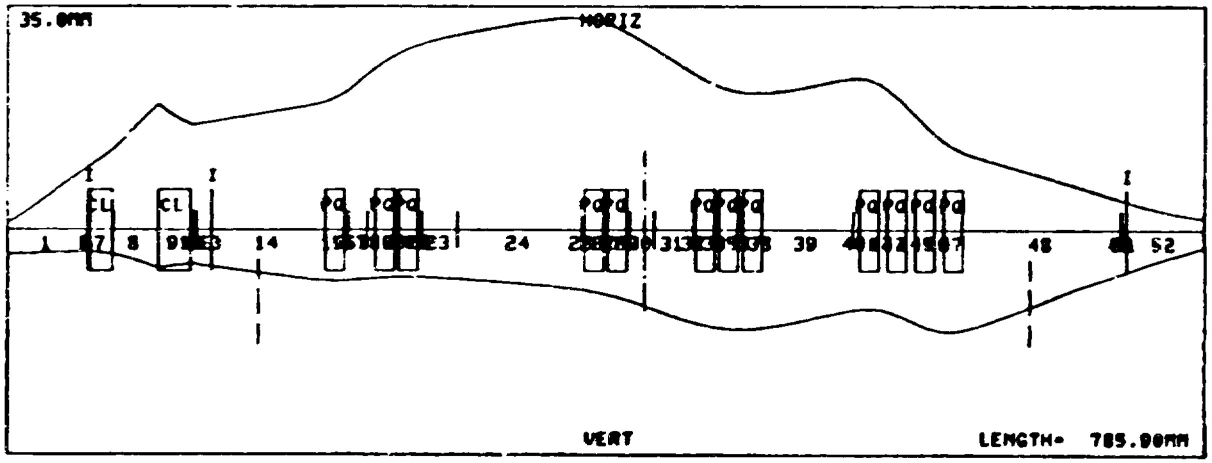
CONCEPTUAL DRAWING
SUBJECT TO CHANGE
LOS ALAMOS
INJECTOR
PHYSICS
INTERFACE

4. GTA-LEBT Baseline Design

The design of the GTA-1 LEBT was done using the TRACE code. In the accompanying diagram the labels "PQ" indicate the position of Permanent Magnet Quadrupoles, "I" indicates the position of neutralization change and "CL" the position of column elements. The Neutralization of the beam by use of Xenon results in a sensitivity of the design to beam current. Since complete neutralization cannot be maintained throughout the entire beam path (a condition occuring in the acceleration column and RFQ entrance) the design must be confirmed experimentally.



- Design Based on ATS LEBT
- Beam Mapped from Source Slit to RFQ Match Point
- Twelve 1/2" Thick SmCo Quadrupoles
- Column Focus Electrode (25 keV)
- Column Final Acceleration Electrode (100 keV)
- Horizontal and vertical beam profiles vs distance

GTA-1 LEBT BASELINE DESIGN

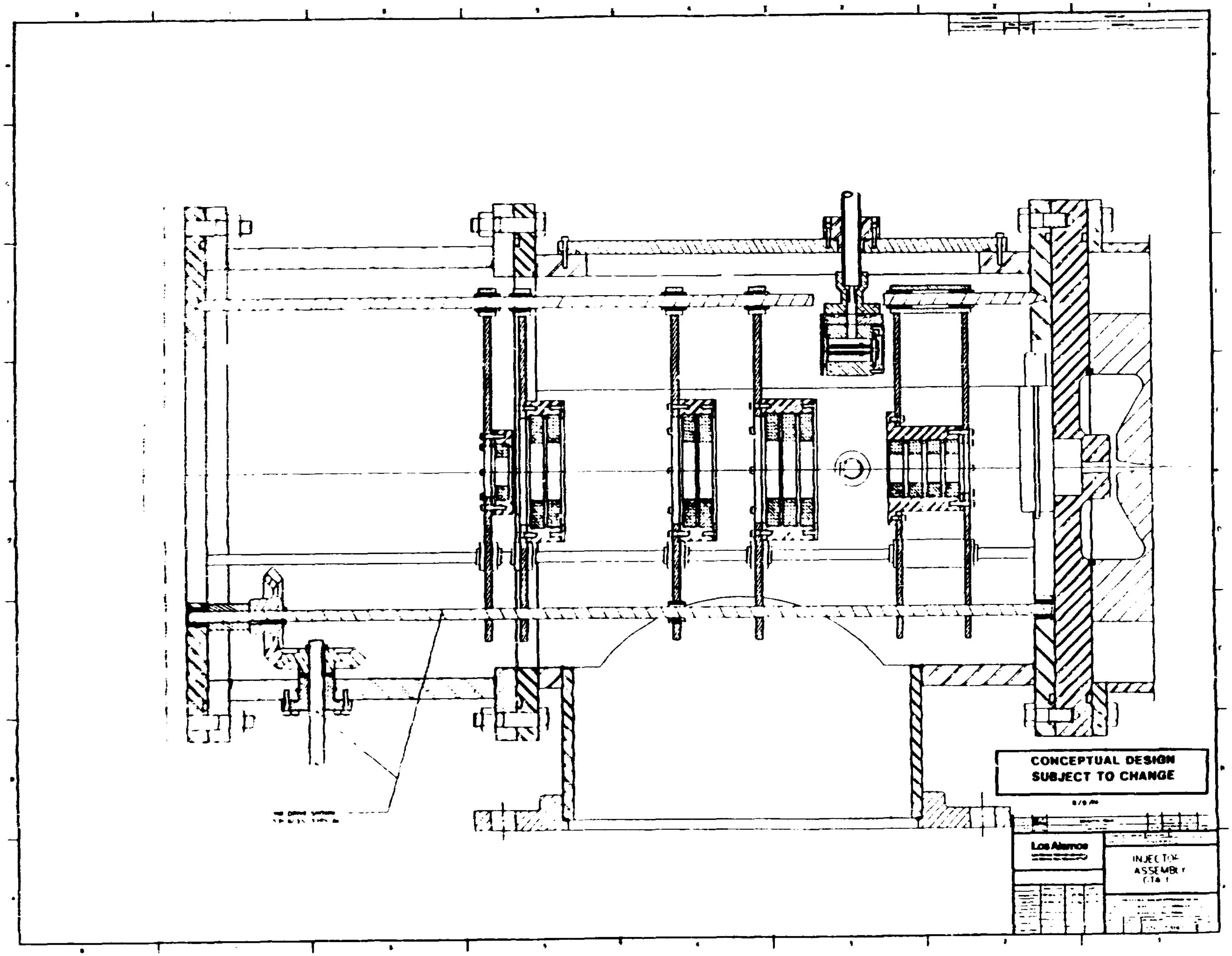
5. GTA-1 Ion Injector Assembly Drawing

The general layout of the GTA-1 Ion Injector is shown in the assembly drawings. First the ions will be accelerated to a potential of 25 kV, pass through a focusing electrode, and then be accelerated to 100 kV. The electrodes are being designed so that it will be possible to enclose PM quadrupoles within the electrodes if necessary. Calculations have shown that adding such quads could improve the ATS design, although the present physics footprint does not include them.

The ion beam will be stabilized by using Xenon gas at a pressure of about 2×10^{-7} torr in the acceleration column and in the LEBT. The PM quads will be covered with cooling shrouds and will be movable along the beam axis for maximizing the coupling to the RFQ. The two main diagnostic tools in the injector will be the mini emittance scanner and Faraday collector developed for ATS. The early test plans call for investigating other diagnostic techniques such as wall current moniters, video, and fiber optics.

The injector will mount directly on the end wall of the RFQ but will include a gate valve to isolate the injector from the RFQ. The vacuum will be maintained with cryo pumps. A gate valve will isolate the injector from the vacuum system.

Early experiments with alternative source-slit geometries may require a change in the overall length of the LEBT. This changes can be easily accomplished by changing the length of the spool piece between the LEBT vacuum box and the acceleration column.

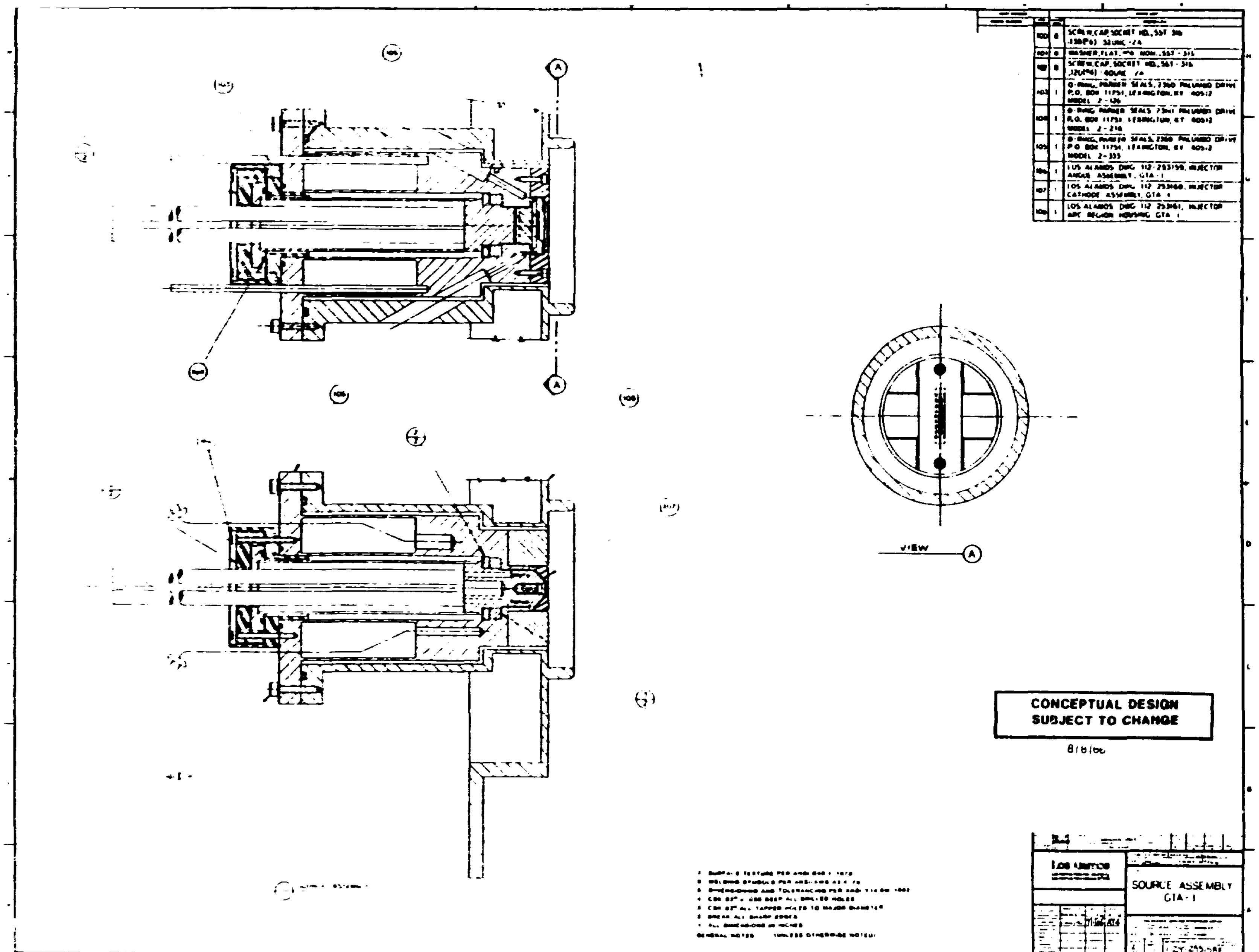

CONCEPTUAL DESIGN
SUBJECT TO CHANGE
Los Alamos
INJECTOR
ASSEMBLY

6. GTA-1 Ion Source Assembly Drawing

The Dudnikov H^- source is a Penning hydrogen discharge to which cesium has been added to enhance the production of H^- ions. Cesium vapor will be transferred from an independently controllable oven to the discharge anode along with the hydrogen. The hydrogen flow rate will be controlled by a piezoelectric valve and by the size of the exit slit. The cathode-anode geometry is essentially that developed by Dudnikov as adapted by Allison on the ATS.

One of the major design changes implemented on the BEAR project by Shubaly was packaging the ion source as a cartridge. This design should be able to meet the "g" load requirements of flight and will be easily replaceable in the event of source failure. The cartridge concept has been adapted for GTA.

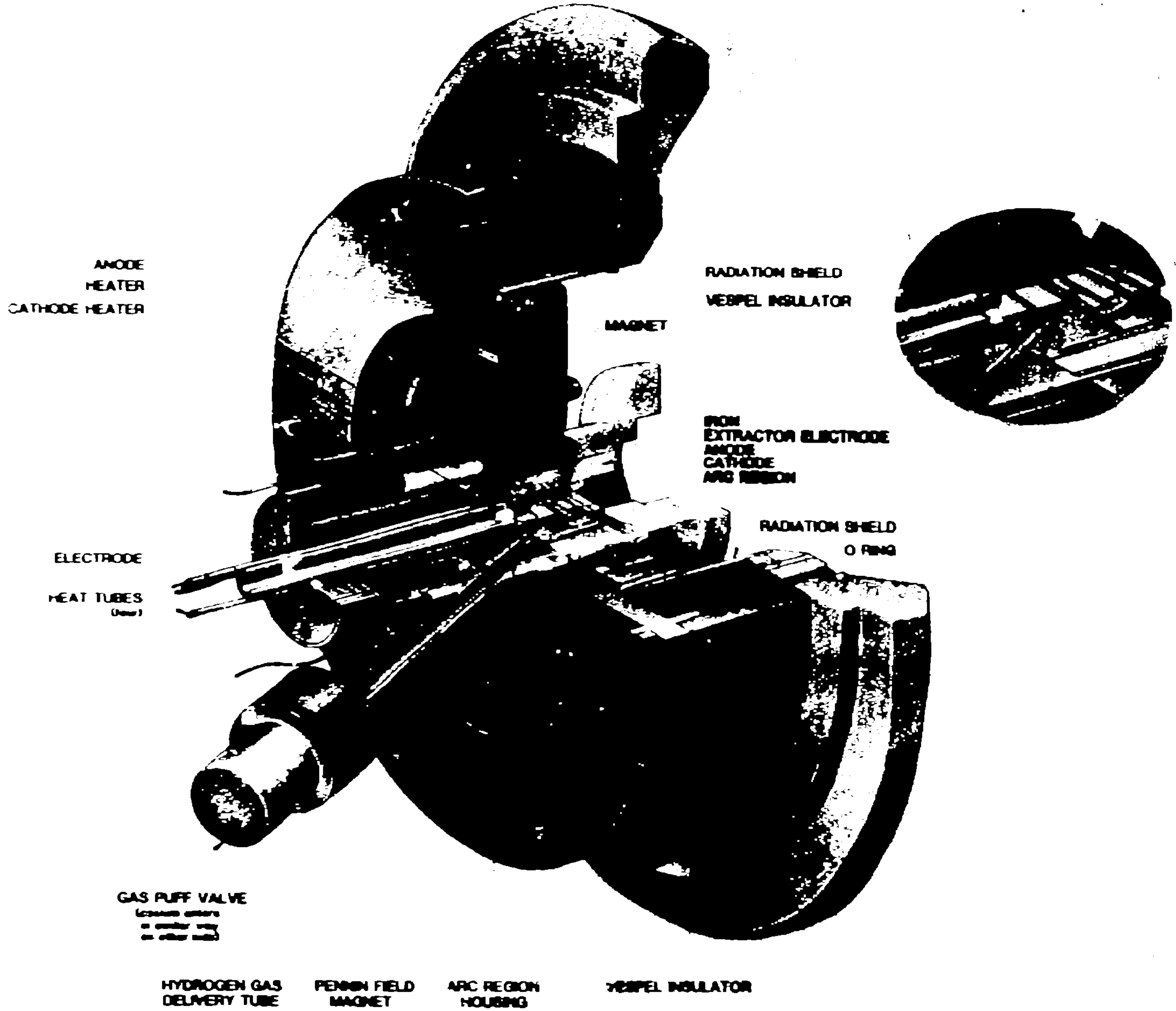
The Penning magnetic field will be generated by permanent magnets and will be varied by using trim coils.



VIEW A
CONCEPTUAL DESIGN
SUBJECT TO CHANGE
SOURCE ASSEMBLY
GTA-1

7. Artists Conception Of The GTA-1 Ion Injector

This pictoral representation of the Ion Source is intended to aid in the description of the source. The various major components of the source are shown except for the cesium oven, which is hidden in this view.



H^- SOURCE ION
CANISTER PACKAGE
GTA-1

8. GTA-1 Injector Hydrogen Flow Control

The production rate of H^- ions in a Dudnikov source is dependent in a complex manner on the relationship of several arc parameters. The hydrogen pressure, cesium pressure, cesium coverage of the electrodes, arc voltage and current, and applied magnet field are all related in the producion of the H^- ions. Part of the relationship is the temperature of the electrodes in the region of the discharge.

By establishing precise control of the flow rate of hydrogen through the discharge region, it is hoped that greater control of the discharge conditions will be maintained. Work with a piezoelectric valve made by Lasertechnics has shown that the valve will give good control of the hydrogen pressure. The minimum pulse length is felt to be determined by the pressure diagnostics and not by the valve. Work in developing a high-speed pressure gauge is now in progress.

GTA-1 ION INJECTOR

HYDROGEN FLOW CONTROL

Based on Lasertechnics Piezoelectric Valve

Has Demonstrated

1. Gas pulse width variable to 100 microsec.
2. Repetition rate 500 pps.
3. Inlet pressure up to 10 Atm.
4. Power Dissipation 15 mW.

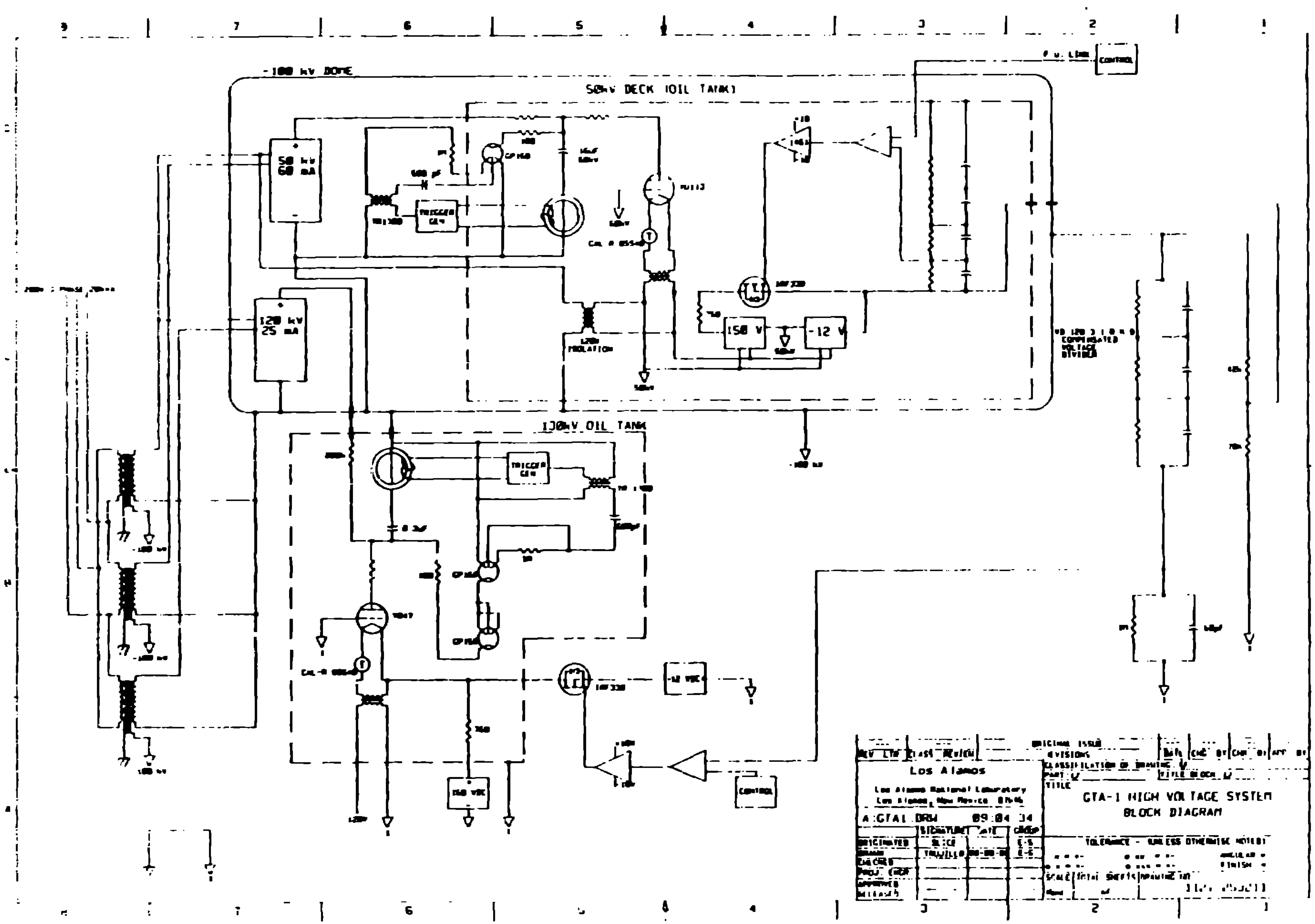
9. GTA-1 Ion Injector High-Voltage System

The high-voltage system departs in some details from the ATS design. For GTA the ion source will be pulse biased to -100 kV (dome voltage), and the extractor will be pulsed positive, relative to the source, by 25 kV when it is desired to extract ions from the source. Since the duty factor for GTA-1 is 0.1%, a small power supply will continuously charge a capacitor for both the extractor and the dome. A high-voltage tube, used in grounded grid configuration, will be used to regulate the voltage supplied by the capacitator. The rise time of the output from the injector will be determined by the build-up of neutralization in the LEBT as long as good design practice is followed in the source pulser.

The system will be provided with crowbar capability in the event that an arc-over of the injector is detected. This protection should guarantee that less than 10 J of energy is dissipated in an arc. Complete shutdown of the system will occur if the computer detects a series of arc events.

In the present design, the capability of leaving the dome voltage continuously on will be provided because current would be drawn only when ions are extracted. This mode of operation may not be desirable since the probability of arc-over is increased.

Power will be supplied to the dome via an isolation transformer. The size and weight of this transformer could be reduced by operating at high frequency; however, in the interest of cost and availability, it was decided to work with 60 Hz power.



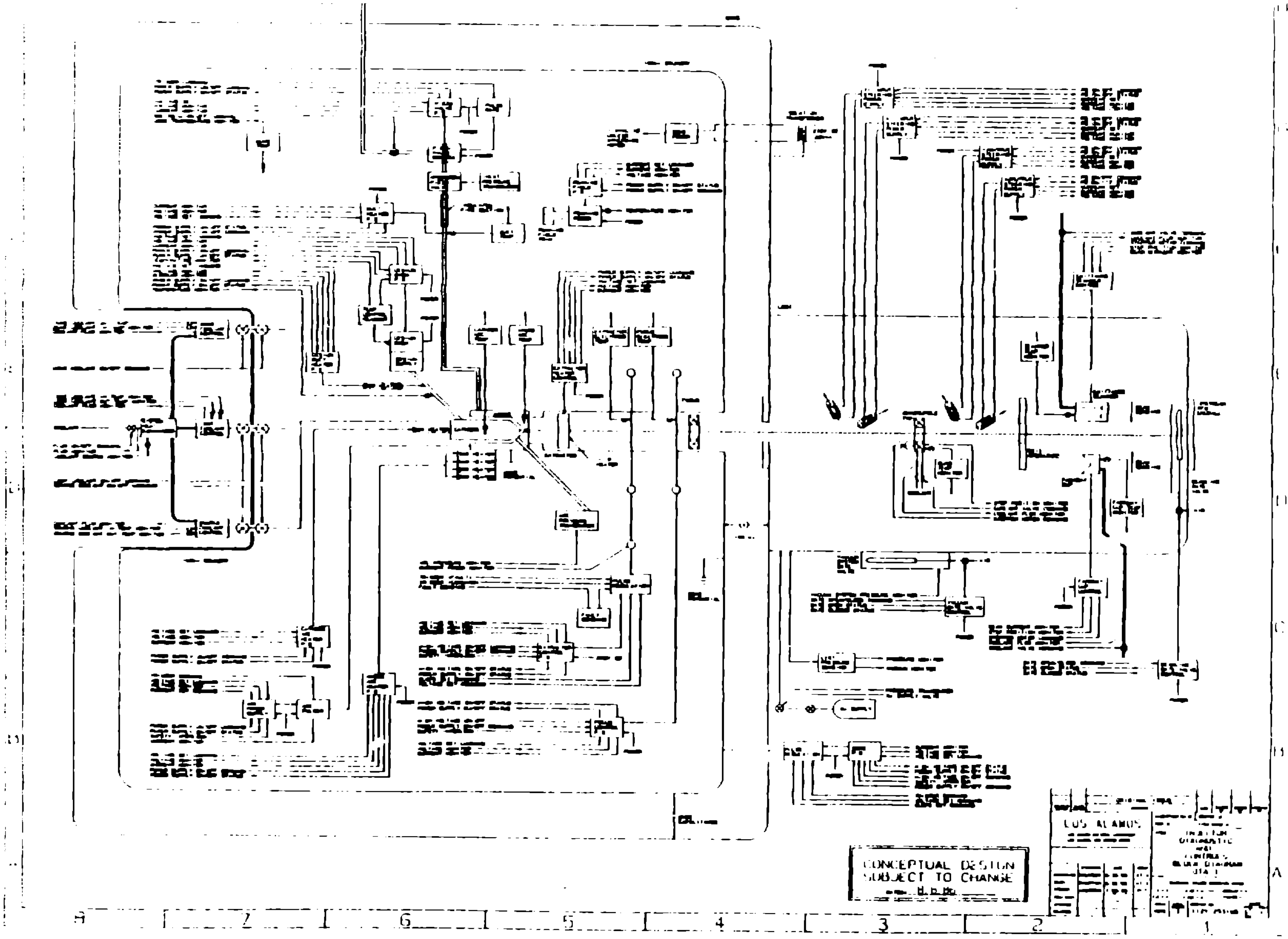
-100 kV DOME
50kV DECK (OIL TANK)
50 kV
60 mA
120 kV
25 mA
TRIGGER GEN
CONTROL
150 V
-12 V
COMPENSATED VOLTAGE DIVIDER
130kV OIL TANK
TRIGGER GEN
-12 VDC
150 VDC
CONTROL
Los Alamos
GTA-1 HIGH VOLTAGE SYSTEM
BLOCK DIAGRAM

10. GTA-1 Ion Injector Control System

This drawing of the control system in schematic form gives some idea of the complexity of the controls necessary to operate an ion injector. The drawing has become the focal point of the controls development work on the injector. Since the work in this is evolving, this drawing must be regarded as a working drawing at the present time.

The diagnostic and control system can be divided into two components dependent on whether or not the element under discussion is located at system ground potential or at dome potential. Signal transfer across the dome potential will be accomplished by fiber optics.

Details of the control system will be presented during the discussion of the controls system. The general intent is to provide three main control modes. The first mode would allow full operator control for maintenance purposes. The second mode would provide operator control via system algorithms, and the third mode would consist of automatic computer control with operator monitoring.


CONCEPTUAL DESIGN
SUBJECT TO CHANGE
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11. GTA-1 Ion Injector Status

The present status of the work on the GTA-1 Ion Injector can be summed up by the status of the drawing tree in Appendix D.

The ion source drawings are complete, and a cold model of the source has been fabricated and fabrication of the first arc source has begun. Some of the diagnostic tools such as the mini emittance scanner and Faraday cups are being taken directly from the ATS design. They are also under fabrication. The design of many other components of the system is under way.

Many of the components such as the power supplies, capacitors and series regulation tubes have been ordered and delivery is expected by mid September.

Operation of the ion source is scheduled to begin in early September to get experience with the source. As other components of the system become available they will be placed into operation.

III.B. RADIO-FREQUENCY QUADRUPOLE (RFQ)

III. B. GTA RFQ

III. B. GTA RFQ

III. B. GTA RFQ

1. <u>Introduction</u>

The role of the RFQ in the accelerator system is to provide a transition from the low voltage (100 keV) dc injector to the Drift Tube Linac which requires an input energy of 2 MeV. While accelerating the beam, the RFQ adiabatically bunches and focuses the beam with minimal emittance growth

Physics and RF Quantities

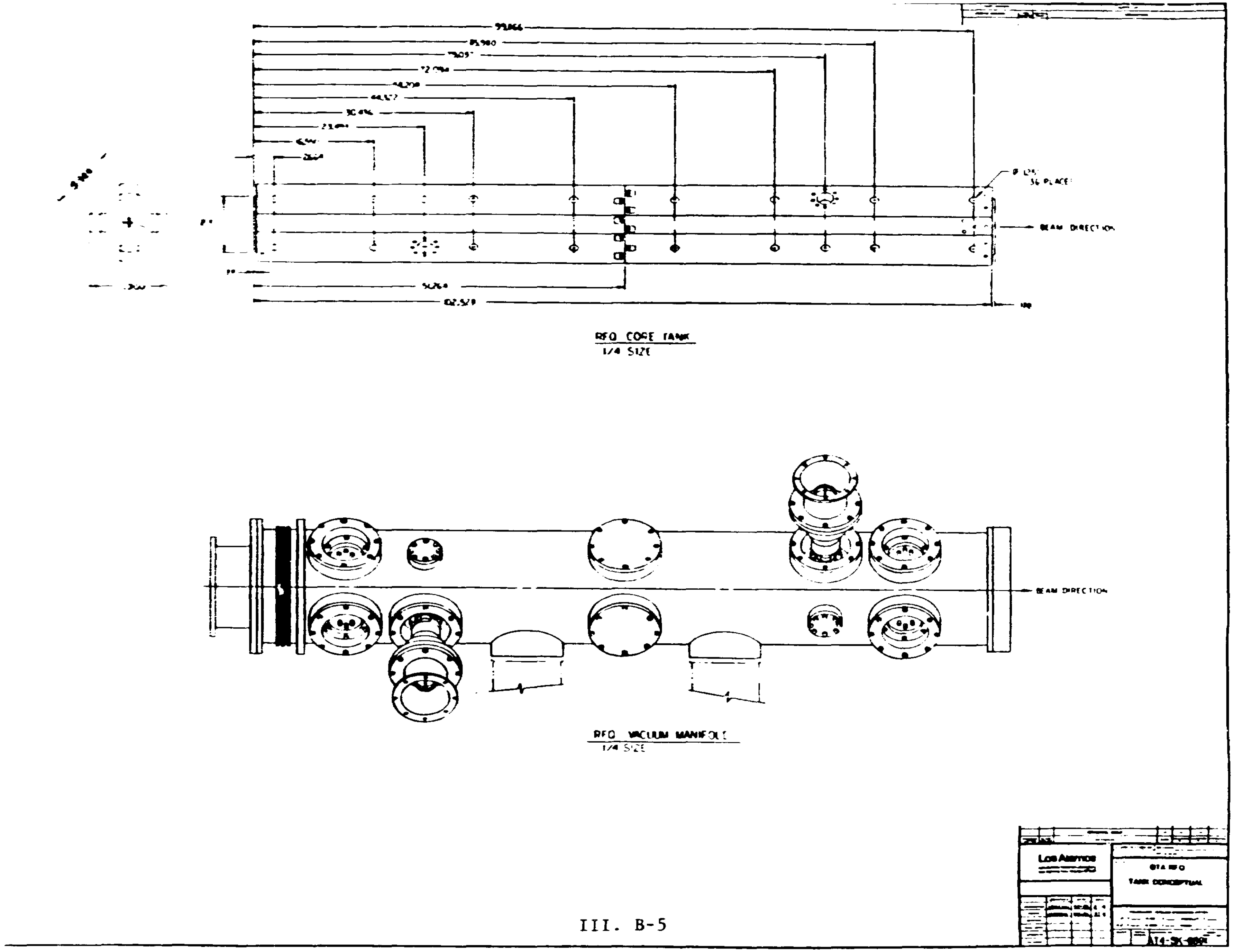
Type of Particle	H^-
Frequency	425 MHz
Injection energy	0.10 MeV
Energy at end of Shaper	0.27 MeV
Energy at end of Buncher	0.49 MeV
Final energy	2.07 MeV
Input current	120 mA
Output current	106 mA
Peak beam power	207 kW
Input emittance	0.017 cm-mrad (rms,n)
Output emittance	0.019 cm-mrad (rms,n)
Peak surface field	1.8 x Kilpatrick (36.0 MV/m)
Intervane voltage	0.079 MV
Vane capacitance	120 pF/m
Synchronous phase at end of buncher	-45°
Final synchronous phase	-37°
Modulation at end of buncher	1.475
Final Modulation	1.798
Total number of cells	252
Copper and beam power (106 mA)	534 kW
Duty factor	5% max.
Pulse length	2 msec max.
Operating pressure	1.0e-06 torr max.
Rf drive type	1.625 in. dia. loops, 2 plcs., opposite quad'rts.

Dimensional Quantities

Minimum aperture	2.26 mm
Aperture radius, end of buncher	2.84 mm
Final aperture radius	3.29 mm
Minimum longitudinal radius of curvature	1.60 cm
Radial matching length	3.09 cm
Shaper length	79.35 cm
Gentle buncher length	28.20 cm
Accelerator length	148.67 cm
Total length	259.31 cm
Cavity inner length, end-wall to endwall	260.41 cm

2. Physical Configuration

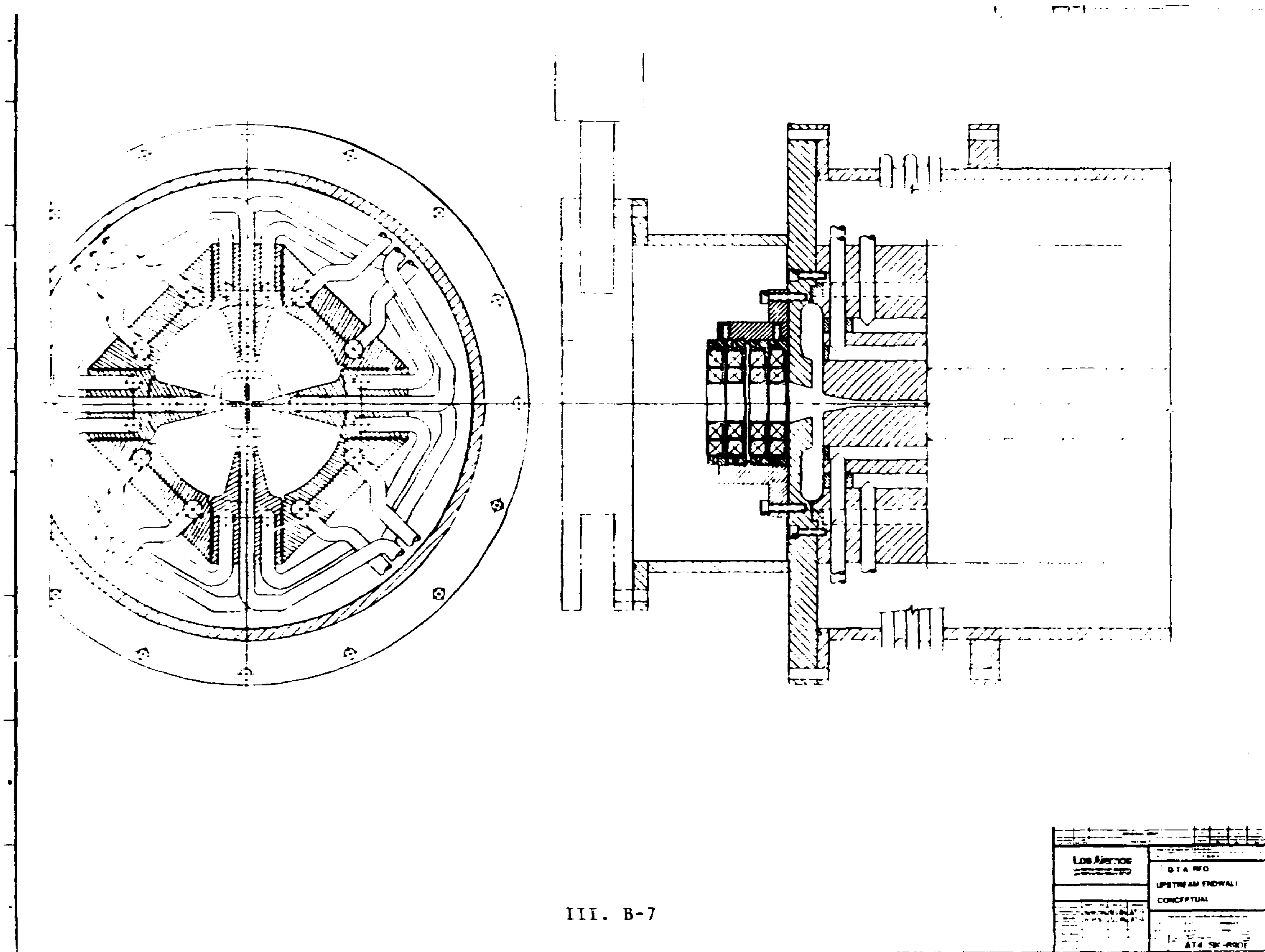
The RFQ consists of two subassemblies, joined in a manner that will ensure mechanical and thermal stability and enhance the accuracy of fabrication. These two parts are called the coretank and the vacuum manifold. The coretank subassembly is composed of two elements, vanes and skirts. The vane elements have the accelerating/focusing geometry machined into their surface, and the skirt elements provide closure of the RFQ cavity and structural integrity of the assembly. The core tank is an assembly of eight vane and eight skirt elements, consisting of four each in cross section and two each longitudinally. The core tank is enclosed in a vacuum manifold, which eases the job of maintaining vacuum integrity of the rf cavity by reducing the total length of vacuum joint required. The vacuum sealing problem is restricted to only circular ports in the manifold tank, which are needed in order to pass coolant and rf power to the core tank assembly.



RFQ CORE TANK
1/4 SIZE
BEAM DIRECTION
RFQ VACUUM MANIFOLD
1/4 SIZE
BEAM DIRECTION
Los Alamos
GTA RFQ
TANK CONCEPTUAL

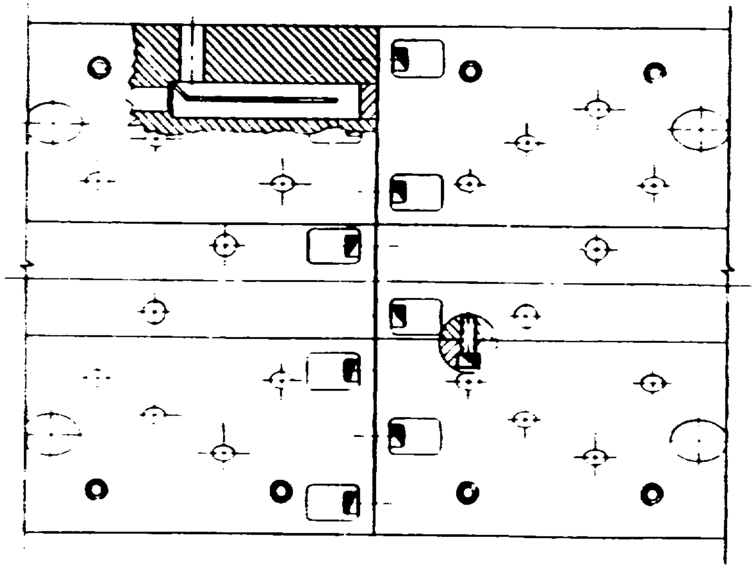
3. Low-Energy Interface

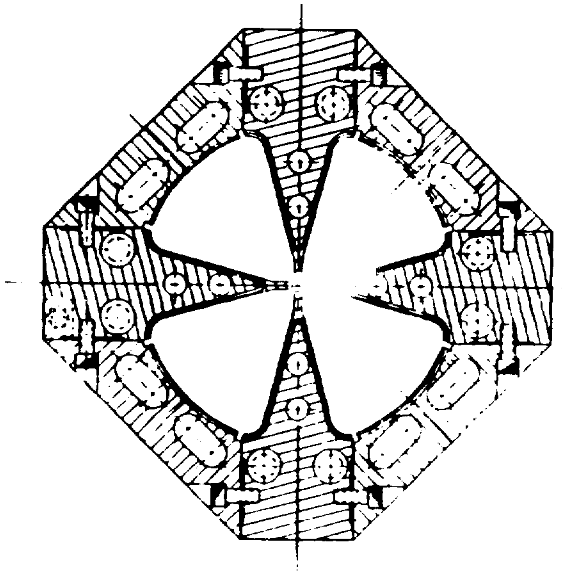
At the low-energy end (upstream end) the RFQ interfaces with the low energy beam transport (LEBT) section of the injector. The interface is accomplished through a common end-plate that attaches to the core tank assembly, the vacuum manifold, and the last set of focusing magnets in the LEBT. A machined cavity is required in the plate adjacent to the RFQ vane ends to allow for tuning of the structure. The exact dimensions of the cavity are set during the tuning process before the RFQ is run at high power. Mechanical indexing via dowel pins will be provided to ensure good alignment between the components.


G T A RFQ
UPSTREAM ENDWALL
CONCEPTUAL

4. Coretank Center Joint

The coretank is machined in two sections longitudinally for better accuracy. The joint between the sections occurs at the end of cell No. 145 in the accelerating section of the RFQ. This is slightly (0.6 cm) downstream of the geometric center of the tank The joint is placed at a cell end to ease fabrication. The joint uses a flexible rf contact placed in a racetrack-shaped groove running along the inner periphery of the cavity. The contact will allow low-current power transfer across the joint if need be. Since theoretically all current flow is tangential, the required capacity at the center joint is very small.





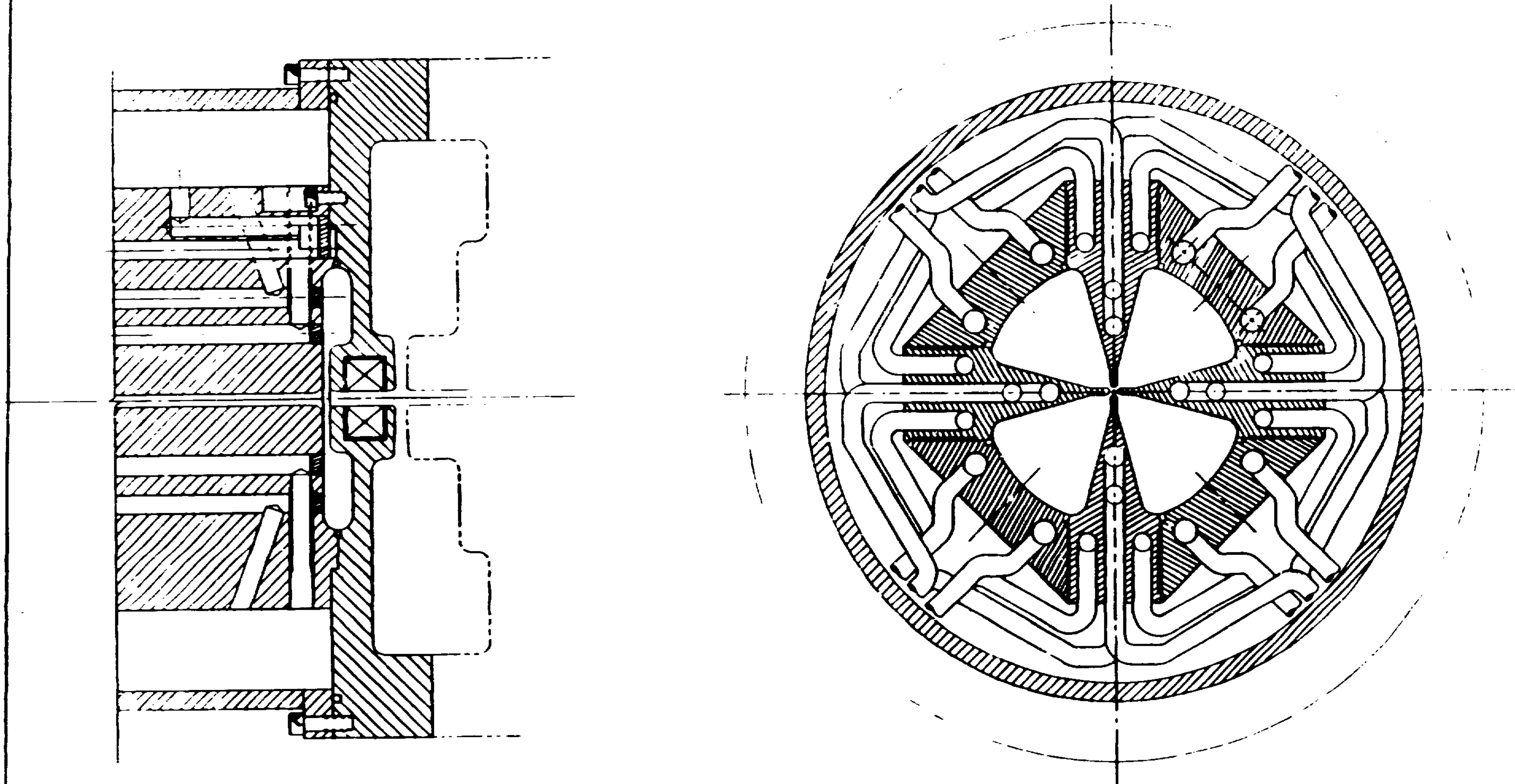
III. B-9

Los Alamos

CONCEPTUAL

5. High-Energy Interface

At the high-energy (downstream) end, the RFQ interfaces with a bunching cavity. The function of the bunching cavity is to provide a better match between the RFQ and the DTL. This interface is similar to the upstream interface with the LEBT except that the end plate of the RFQ is actually the buncher itself. This is necessary because of the short drift-space limit between the end of the RFQ vanes and the first focusing magnet of the buncher. Here again mechanical indexing via dowel pins will be provided to ensure good alignment between the components.



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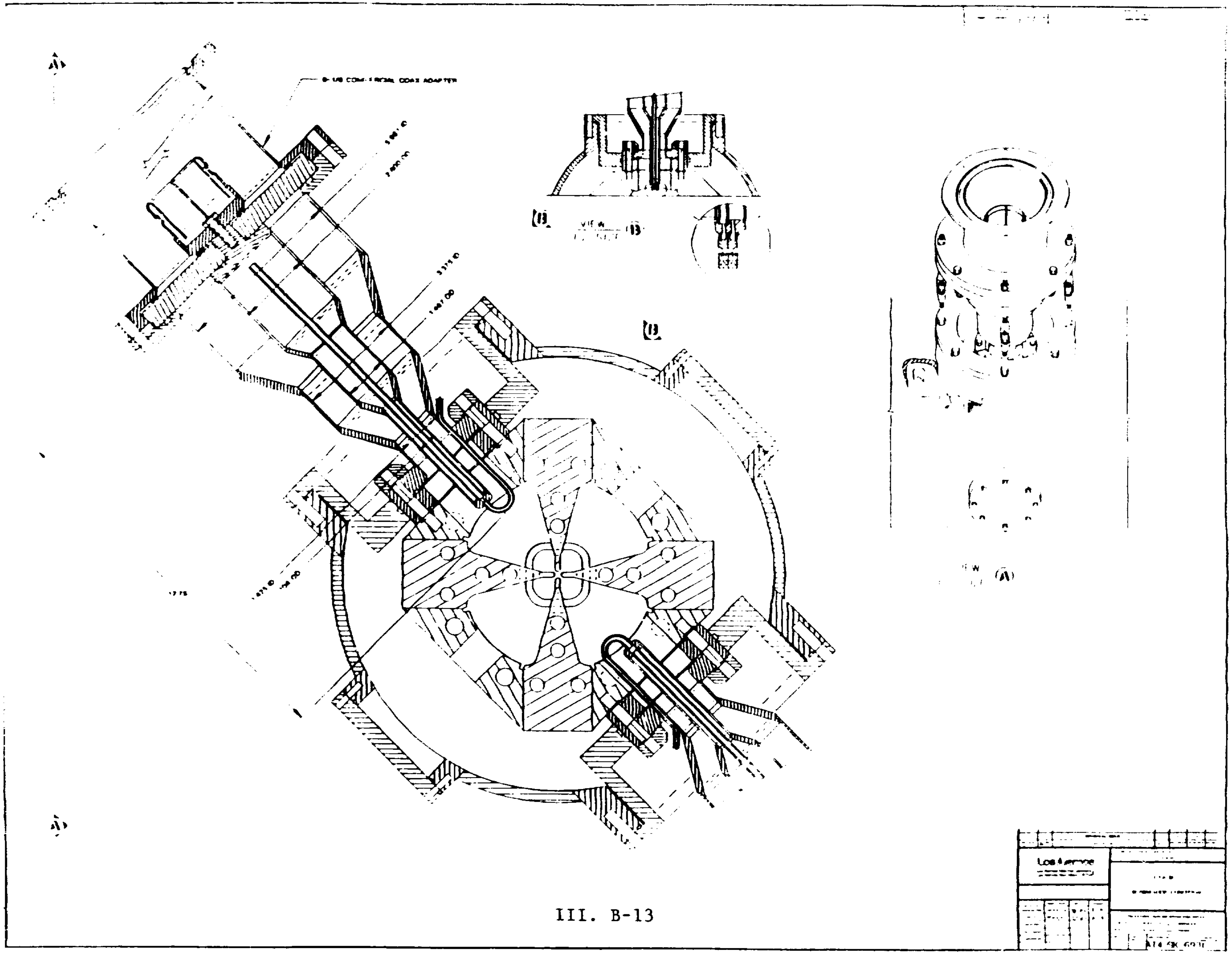
DOWNSTREAM ENDWALL

CONCEPTUAL

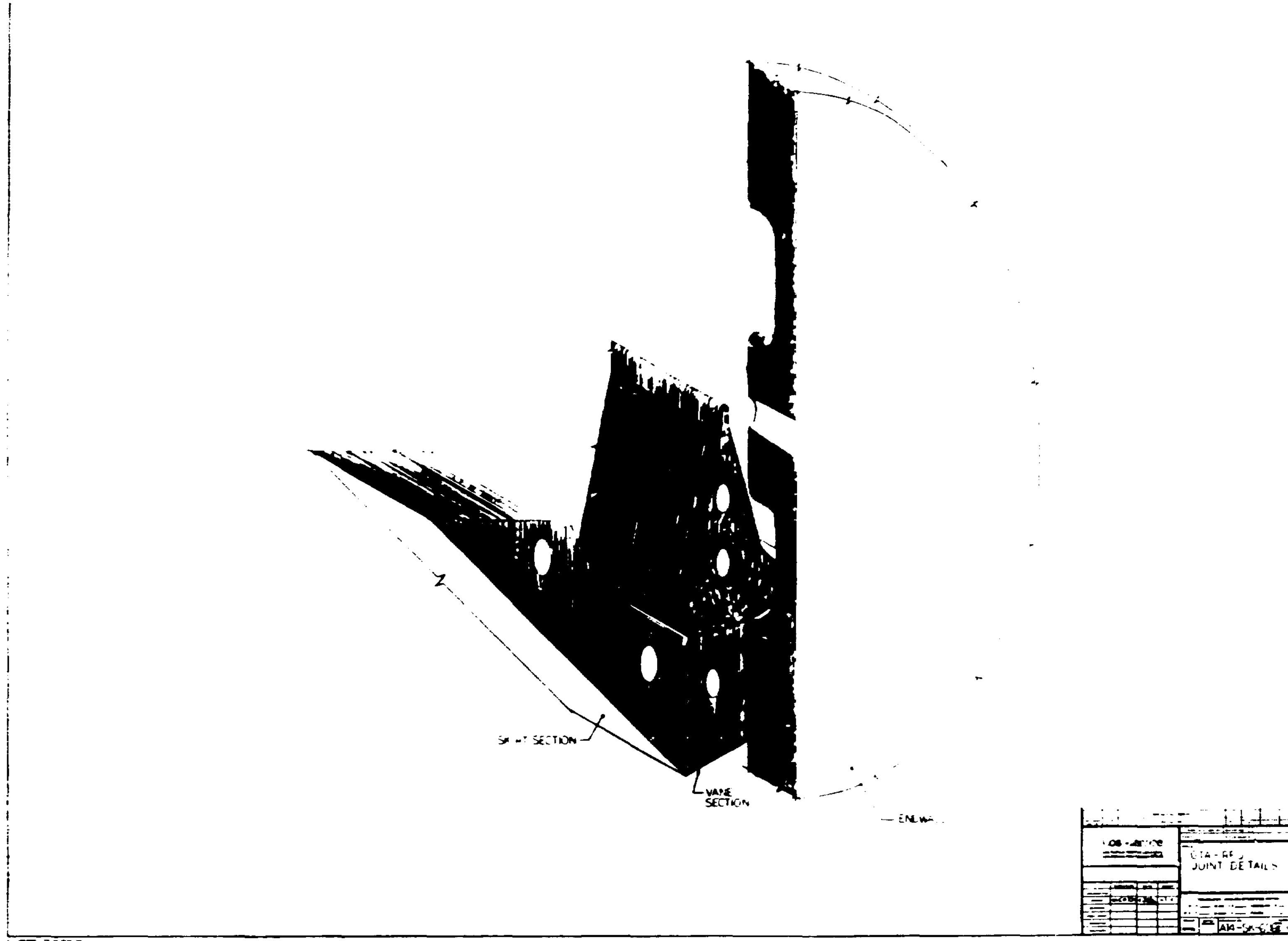
6. RF Drive Loops

The GTA RFQ will be a loop-driven structure. The RF drive loop allows transition from 3.125 in. coaxial line to a diameter that will fit into the RFQ quadrant. The minimum size of the tapered drive loop is about 1.625 in. The conceptual design calls for 2 drive loops, to be placed near the one-half power point. The physical location is one-half wavelength downstream of the geometric center (65.15 in. from the upstream end) exactly between the 5th and 6th set of vane coupling rings. The drive loops will be placed in opposite quadrants of the RFQ for symmetry. The required peak power is about 275 kW for each drive loop. Two drive loops will be sufficient for the short pulse lengths associated with GTA Phase-1, but there is some concern that four loops may be required for Phase-2 to avoid electrical breakdown. At the 5% duty factor, however, a good deal of extra complexity is introduced to the RFQ system by additional loops (more power splitters, phase shift hardware etc.) as well as added complexity to the control system. Since the mechanical design differences are trivial (i.e. just more of the same hardware), the two-drive concept is proposed for the preliminary design. An experimental program is under way to evaluate the actual power-handling capabilities of the loop and the design will be revised if required.



7. Static Tuning

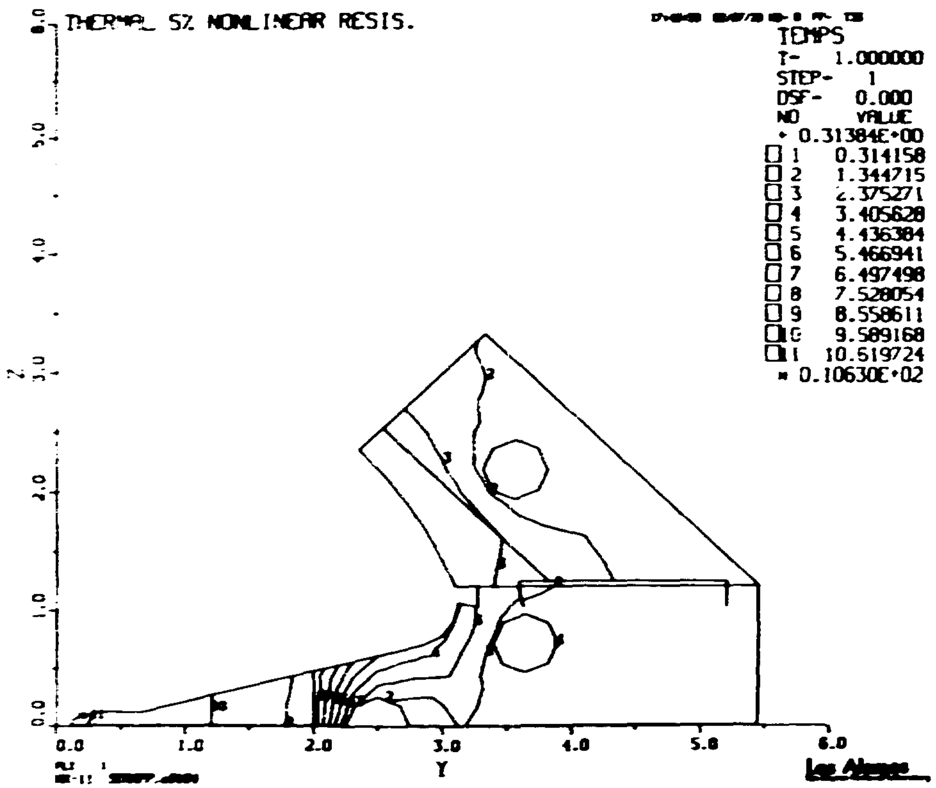
The RFQ is required to operate at 425 MHz ± 20 kHz in order to match the DTL frequency envelope. The RFQ will be tuned at room temperature in the structures lab. The tuning procedure corrects frequency errors in the fabricated components due to machining inaccuracies as well as unpredictable small effects such as vacuum and drive-loop penetrations and vane coupling rings. The tuning process consists of obtaining the proper frequency as well as a flat and stable field distribution along the length of the machine. The GTA RFQ will be tuned by removing material from the outer radius of the wall (on the skirt elements) in each quadrant to approach the design frequency from the high-frequency side. This requires that the resonant frequency of the quadrants be higher than the design value initially so that material may be removed during the process. The tuning will be done in steps, with disassembly of the section and machining required at each step.

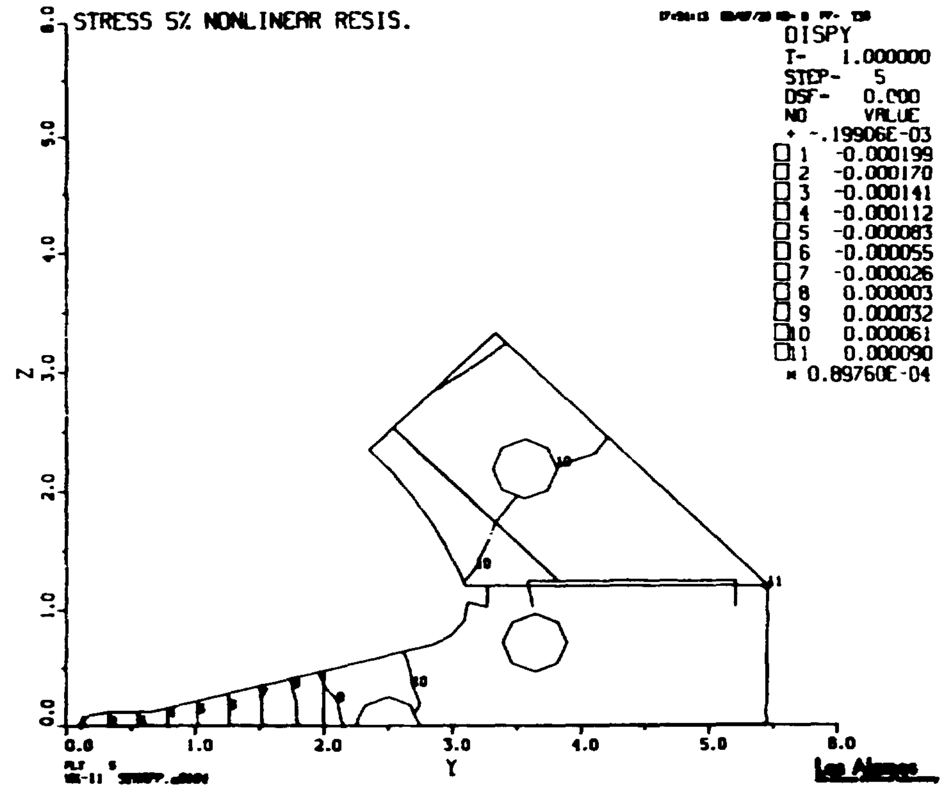

VANE
SECTION
JOINT DETAILS

8. <u>Frequency Control During Operation</u>

A. Nominal Temperature and Vanetip Displacements.

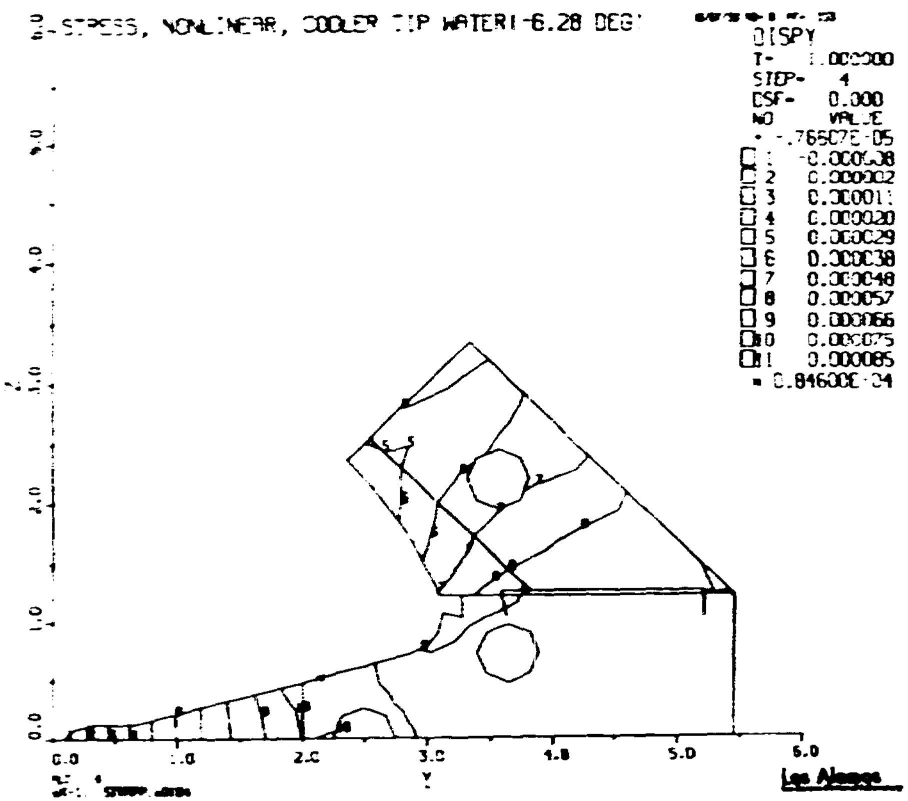
The design frequency will be maintained during operation by variations in the machine coolant temperature. The resonant frequency of the RFQ is extremely sensitive to changes in vane to vane gap that occur as the temperature of the structure varies. Design studies on the computer predict a sensitivity of roughly 2 MHz/mm. Since the maximum frequency deviation from the design value is about 20 kHz, vane-tip spacing must be controlled to within 0.0004 in. This is quite easily done by slightly varying the coolant temperature, provided that the coolant channels are properly located. Analysis shows that the maximum temperature excursion above the coolant temperature at 5% duty will be about 11°F, for the case where all coolant is supplied at the structure's stress-free temperature (the temperature at which low power tuning was done). The resulting frequency shift for this condition would be about -22.2 kHz.

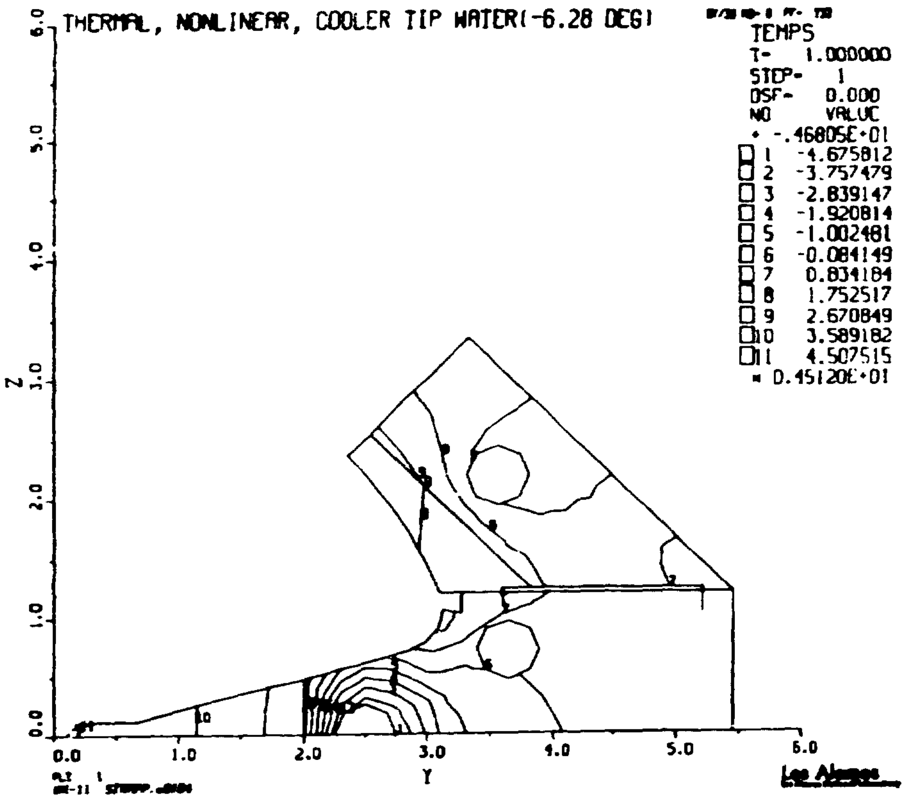

THERMAL 5% NONLINEAR RESIS.
TEMPS
T- 1.000000
STEP- 1
DSF- 0.000
NO VALUE
+ 0.31384E+00
1 0.314158
2 1.344715
3 2.375271
4 3.405828
5 4.436384
6 5.466941
7 6.497498
8 7.528054
9 8.558611
10 9.589168
11 10.619724
* 0.10630E+02
Z
Y
Los Alamos


STRESS 5% NONLINEAR RESIS.
DISPY
T- 1.000000
STEP- 5
DSF- 0.000
NO VALUE
+ -.19906E-03
1 -0.000199
2 -0.000170
3 -0.000141
4 -0.000112
5 -0.000083
6 -0.000055
7 -0.000026
8 0.000003
9 0.000032
10 0.000061
11 0.000090
* 0.89760E-04
Z
Y
Los Alamos

B. Correction of Frequency to 425 MHz

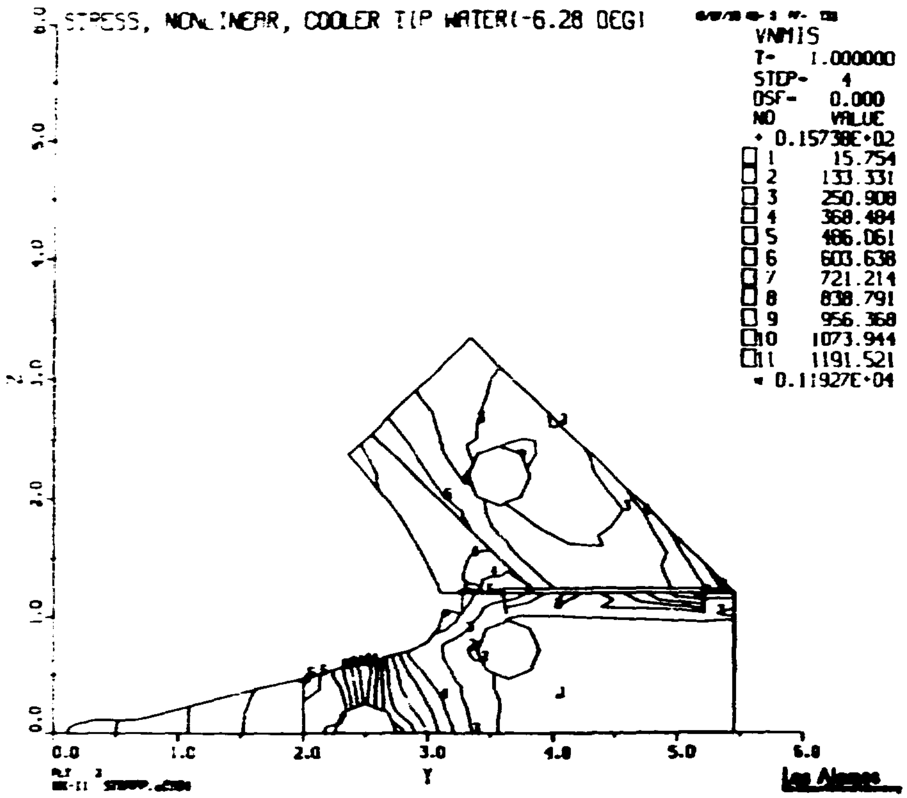
The required change in vane-tip coolant temperature to correct this frequency shift is about -7°F. This analysis is fairly crude because there is also some frequency shift of the quadrant due to volume changes as well as the vane-tip spacing mentioned. In addition, thermal induced errors usually add to the volume change. However, these volume effects are about 10 times less sensitive than vane-tip effects.

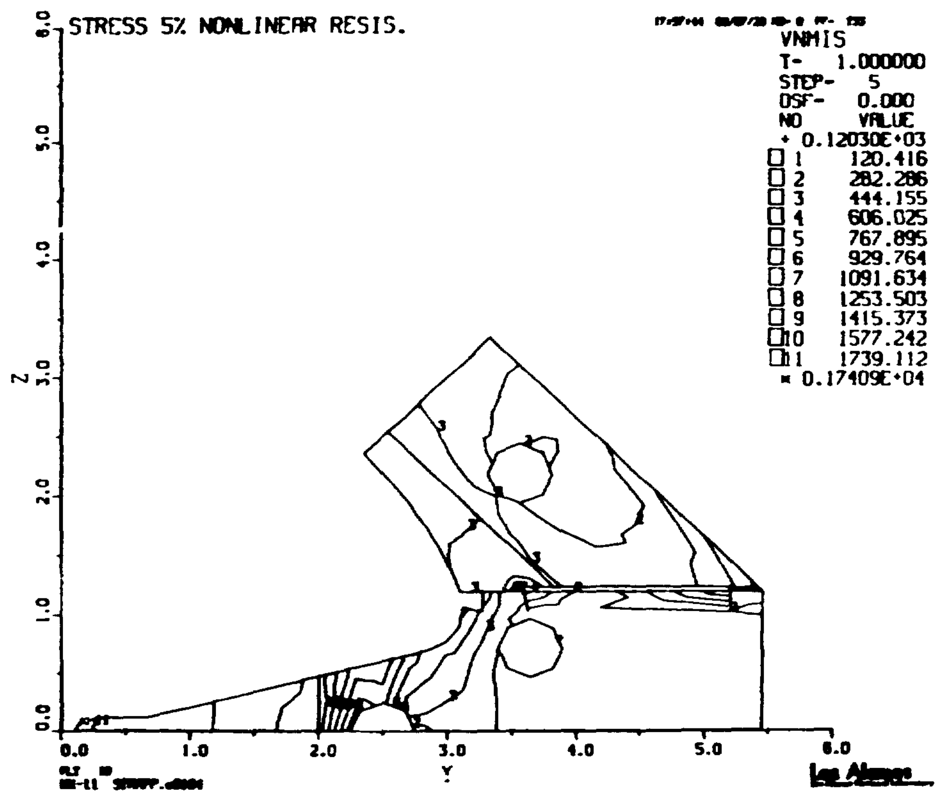

STRESS, NONLINEAR, COOLER TIP WATER(-6.28 DEG)
DISPY
T- 1.000000
STEP- 4
DSF- 0.000
NO VALUE
1 -0.000008
2 0.000002
3 0.000011
4 0.000020
5 0.000029
6 0.000038
7 0.000048
8 0.000057
9 0.000066
10 0.000075
11 0.000085
Z
Y
Los Alamos


THERMAL, NONLINEAR, COOLER TIP WATER(-6.28 DEG)
TEMPS
T- 1.000000
STEP- 1
DSF- 0.000
NO VALUE
+ -.46805E+01
1 -4.675812
2 -3.757479
3 -2.839147
4 -1.920814
5 -1.002481
6 -0.084149
7 0.834184
8 1.752517
9 2.670849
10 3.589182
11 4.507515
* 0.45120E+01
Z
Y
Los Alamos

C. Comparison of Stress Loads

An interesting side effect resulting from lowering the vane temperature to restore design frequency is that the mechanical stress level, shown here as a plot of the von Mises stress contours (units are psi), is also lowered. An alternate method of tuning would be to shift the skirt and vane base (the other two channels shown in the plots) coolant temperature by +8°F. The former method gives a lower overall stress distribution and is preferred if chilled coolant is available.


STRESS, NONLINEAR, COOLER TIP WATER(-6.28 DEG)
VNMIS
T- 1.000000
STEP- 4
DSF- 0.000
NO VALUE
+ 0.15738E+02
1 15.754
2 133.331
3 250.908
4 368.484
5 486.061
6 603.638
7 721.214
8 838.791
9 956.368
10 1073.944
11 1191.521
* 0.11927E+04
Z
Y
Los Alamos


STRESS 5% NONLINEAR RESIS.
VNMIS
T- 1.000000
STEP- 5
DSF- 0.000
NO VALUE
+ 0.12030E+03
1 120.416
2 282.286
3 444.155
4 606.025
5 767.895
6 929.764
7 1091.634
8 1253.503
9 1415.373
10 1577.242
11 1739.112
* 0.17409E+04
Z
Y
Los Alamos

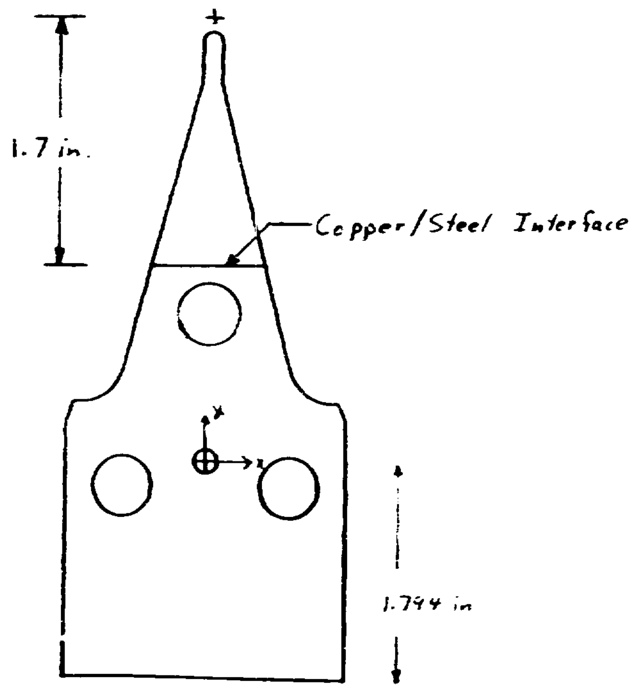
9. Materials Selection

The materials for the GTA RFQ will be copper-clad steel plate for the vanes and skirts and steel pipe for the vacuum manifold. The reason for selecting copper-clad steel was that pure copper vane tips are preferred rather than copper plating to resist electrical breakdown in the high field regions, and steel is known to be easily stabilized mechanically by simple stress-relieving cycles. The bonding of copper and steel will be achieved through explosive cladding. Stress analysis shows the combination to be a good thermal solution as well as a reasonable mechanical solution to the problem of high stability over a long lifetime.

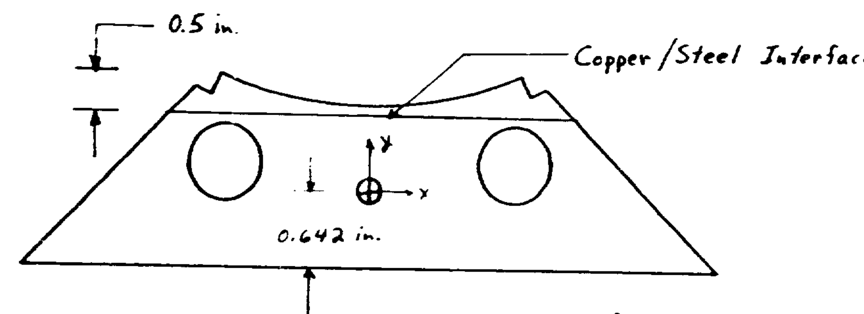
The required 1/2-in.-diameter cooling passages will be roughly 50 drill diameters deep as drilled from each end of the half sections. They will be drilled in the blank stage of the machining process so that no break-outs will occur. Gun drill operations to 100 diameter depth, for holes larger than 3/8-in. diameter, are routinely done with drifts smaller than 0.001-in. per inch-depth guaranteed.

Full Length Assembly

Cross-sectional area	52.25 in.
Moments of Inertia (C.G. is beam axis)	
Ixx = Iyy =	448.92 in.
Polar Moment =	897.80 in.
Weight (volume = 5354.973 in.)	
all copper structure	1729.12 lb.
all steel structure	1518.67 lb.
all aluminum structure	523.72 lb.



Area = 7.128 in^2
I_{xx} = 11.437 in^4
I_{yy} = 2.931 in^4
J = 14.368 in^4



Area = 5.933 in^2
I_{xx} = 1.094 in^4
I_{yy} = 12.675 in^4
J = 13.769 in^4

(Note: all values reflect material removed from cooling passages.)

III.C. DRIFT-TUBE LINAC (DTL)

(Buncher, RGDTL, DTL, HEBT & H^- Beam Stop)

III. C. DRIFT-TUBE LINAC (DTL)

1. Introduction

The 425-MHz drift tube linacs at Los Alamos will operate at 0.1% duty factor in GTA-1 and at 5% duty factor in GTA-2. High peak power densities on the drift tube bodies result from the 5-MV/m accelerating fields developed. Average power densities at 5% duty exceed 2.5 watts/cm^2, a factor of 6 greater than the CW FMIT machine.

A design thrust has been made toward high duty factor capability for these linacs. One reason for this is to develop a machine capable of operation with restricted cooling or in the absence of cooling, i.e. "burst-mode" operation. Thermal studies indicate that OFHC drift tube bodies can operate CW under rf dissipation only, and nearly at CW when beam loss along the boretube is added. Limitations are imposed by the presence of temperature-sensitive rare-earth quadrupoles, which must be protected by thermal gaps. The principal limitation on high duty operation remains the rf seals that join the drift tube stem to the girder, as well as the other rf seals in the system.

Drift tube concepts being developed split the quadrupole singlet into two equal elements between which is nested a fast rf diagnostic probe. The entire assembly is contained within the OFHC body, protected from rf dissipation by a counter-flow cooling jacket. The quadrupoles are isolated from the boretube by a thermal gap. The drift tube is effectively "clamped" against thermal expansion by the combination of the cooling jacket and the diagnostic gap in the boretube.

2. GTA-DTL/Beamstop Design Parameters

The drift tube linac (DTL) for GTA provides the major energy gain for the beam, as well as consuming the bulk of the rf power.

The DTL consists of seven tanks driven by either two or four coaxial lines and rf drive loops and tuned by either two or four motor driven tuners. The tanks are water-cooled and stabilized with post couplers.

The DTL tanks are separated by Intertank Spacers (ITS) which space the tanks apart by specific amounts and which provide freedom of adjustment for aligning the tanks relative to each other.

The mechanical design features include drift tube bodies containing split-singlet quadrupoles and instrumentation probes. The drift tube bore diameters increase as beam energy increases, and the drift tube stem diameters also increase giving a stiffer drift tube suspension in the downstream tanks.

The Phase 1 (GTA-1) H^- beamstop will be used for machine commissioning and tune up. It interfaces with the DTL by means of a beam transport line which includes beam expansion quadrupoles. The surface of the beamstop is graphite clad to reduce activation.

GTA-DTL/BEAMSTOP DESIGN PARAMETERS

Physics

Frequency: 425 MHZ (Nom)

Particle: H^-

Beam Current: 100mA

Energy in: 2.07 MeV

Energy out: 50.27 MeV

Max. Accel. Grad.: 5 MV/m

Max. Focus Grad.: 19 kG/cm

Max. Surface Field: 30 MV/m(1.5K)

Synchronous phase: -30°

Operational

Max Duty Factor: 5%

Max Pulse Width: 2 msec.

Peak Beam Power: 4.819 MW

Peak Copper Loss: 5.239 MW

Total rf power: 10.058 MW

RF Phase Control: ± 0.5°

RF Ampl. Control: ± 0.5%

Structure Temp.: 22.2 °C (Nom)

ΔT (5% DF) : 2.8 °C

Operating Press: 10^{-6} torr

GTA-1 H^- Beamstop

Pulse Power: 5MW

Avg. Power: 5kW

Beamspot Dia: 41 cm

Power Density: 20 W/cm^2 (Max)

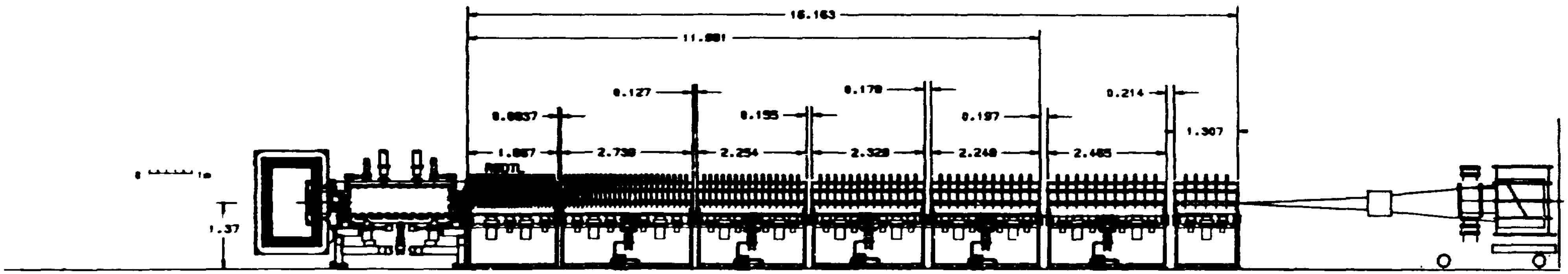
Stopping Medium: Graphite

3. GTA-1 DTL Physics Interface Drawing

The critical physics dimensions and operational parameters for the GTA-1 Drift Tube Linac are shown in this drawing. It includes the mechanical features, such as number of drift tubes, etc. which were assigned to each tank to produce a compact design. Two key criteria used to arrive at this configuration were the maximum accelerating gradient of 5 MV/m and a maximum delivered rf power of 2 MW in a given tank.

The overall length of 16.163 meters for the DTL shows that the physics design supports the need to fit the system into the space shuttle bay with a hinge point between tanks 5-6. The DTL interfaces with a single cell buncher cavity and the RFQ at the upstream end and the beam transport line and H^- beamstop at the downstream end.

The H^- beamstop for GTA-1 is a mobile unit which can be rolled into position to allow beam-on commissioning of each tank in sequence.



	RFQ	T1	T2	T3	T4	T5	T6	T7
NO. DRIVE LOOPS	2	2	4	4	4	4	4	2
NO. CELLS	252	30	26	16	14	12	12	6
NO. DRIFT TUBES		29	25	15	13	11	11	5
NO. POST COUPLERS		14	12	7	6	5	5	2
ACCEL GRAD, Mv/m		2-4.4	4.4	5	5	5	4.7	4.7
FOCUS GRAD, KG/cm		18.333	17.000	19.000	19.000	19.000	18.000	18.000
ENERGY OUT, Mev	2.07	6.67	15.53	23.45	31.34	38.84	46.36	50.27
FACE ANGLE		3°	6°	6°	10°	15°	15°	15°
STEM DIA		2cm	2.5cm	3cm	3cm	3cm	3cm	3cm
BORE DIA		1cm	1.25cm	1.50cm	2cm	2cm	2cm	2cm
Pcu, Kw	309	391	840	624	917	882	858	457
Pb, Kw	197	460	886	792	788	750	752	391
Pt, Kw	506	851	1726	1686	1705	1632	1610	848
PHASE		-35° TO-30°	-30°	-30°	-30°	-30	-30°	-30°

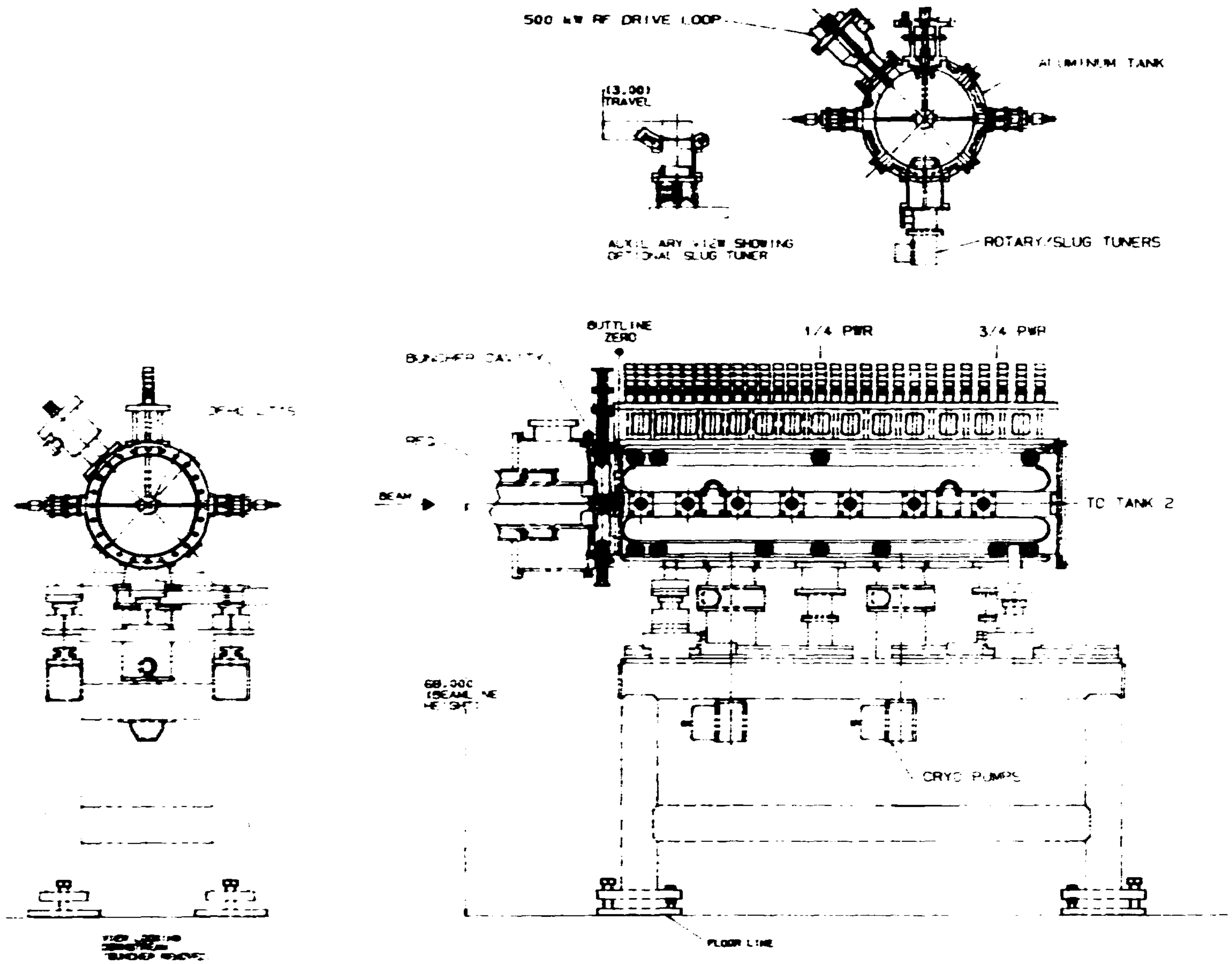
FIG. 6-6

4. DTL Tank Design

This figure shows the first tank of the 7-tank DTL. It is referred to as the Ramped Gradient DTL (RGDTL) because the axial accelerating field is ramped from 2 MV/m at the input to 4.4 MV/m at the output. This ramping is accomplished by highly-coupled post couplers and is one way of matching a high gradient DTL to a RFQ.

The design features in the RGDTL are typical of the other six tanks in the series. The tank barrels are copper-plated aluminum for light weight, high thermal conductivity, and low residual radioactivity. Multiple rf drive loops (2 or 4 per tank) deliver the power via commercial 6-1/8" coaxial lines. The rf drives and tuners are located at balanced power points along the tanks. The drift tubes are supported by single stems from an overhead girder. The girder permits accurate off-line alignment and ease of maintenance. Cryogenic vacuum pumps and rf tuners are located under the tank.

The beamline height is shown for the ATS application. For GTA-1 the beamline height is 60".



RGDTL MACHINE ASSEMBLY

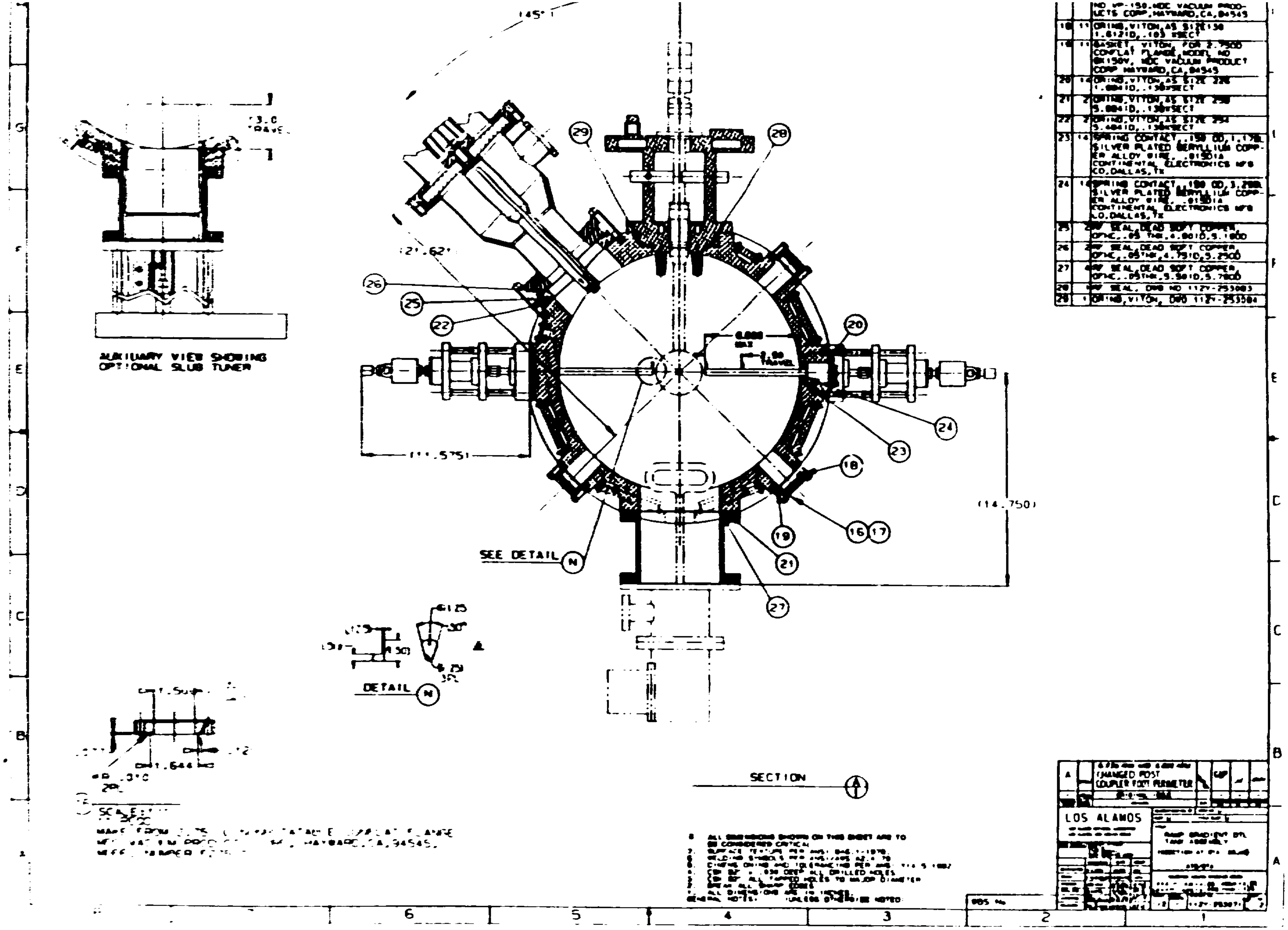
5. Details of GTA-DTL Design

This figure shows an enlarged cross-sectional cut through the RGDTL (which is typical of the other six tanks). One major difference is that the RGDTL requires post couplers with highly selective coupling factors to either end of the drift tube body. Thus the post coupler tips on the RGDTL will be angled tubing to sweep a conical arc, whereas the other tanks will use tabs as shown.

The girder slot is quite shallow and two tuning bars are shown attached. Metallic C-seals or multi-lam seals are used at the various rf joints.

Tuning is accomplished with slug tuners or rotary rf tuners. The rotary tuners are still experimental but may prove to be a better mechanism for vernier tuning of the DTL to follow variations in RFQ resonant frequency.

The aluminum tank is surrounded with cooling channels. These channels carry counter-flowing coolant, and the mass transfer rate of each channel is matched by means of orifice plates.



AUXILIARY VIEW SHOWING OPTIONAL SLUG TUNER
SEE DETAIL N
DETAIL N
SECTION A
(14.750)
(11.575)
(21.62)
(45°)
ORING, VITON, AS SIZE 150 1.612ID, .103 SECT
GASKET, VITON, FOR 2.750OD CONFLAT FLANGE, MODEL NO GK150V, MDC VACUUM PRODUCT CORP HAYWARD, CA, 94545
SPRING CONTACT, .150 OD, SILVER PLATED BERYLLIUM COPPER ALLOY WIRE, .015DIA CONTINENTAL ELECTRONICS MFG CO, DALLAS, TX
RF SEAL, DEAD SOFT COPPER, OFHC
RF SEAL, DWG NO 112Y-253083
ORING, VITON, DWG 112Y-253084
LOS ALAMOS

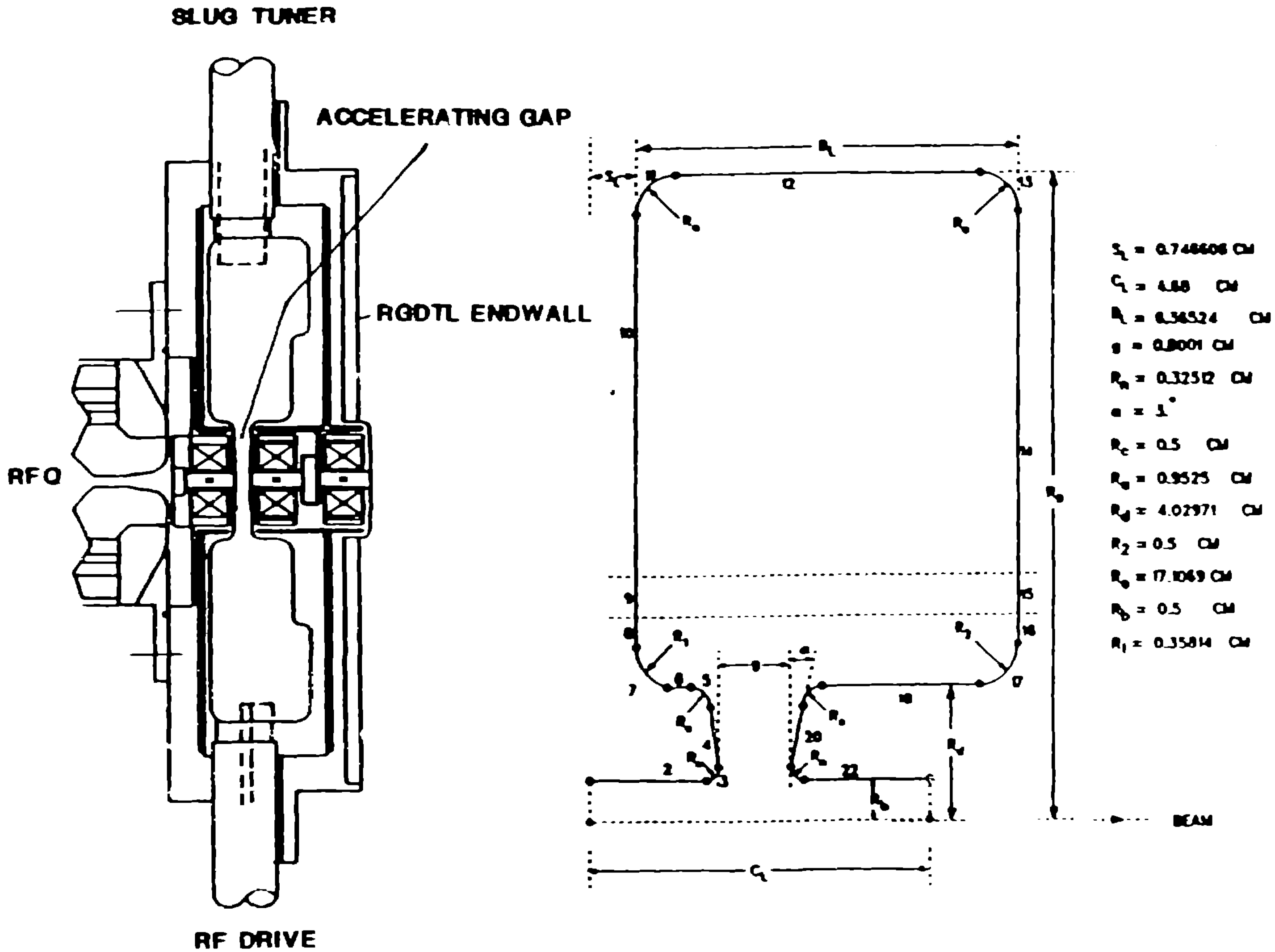
6. GTA Buncher Cavity

The buncher cavity provides longitudinal bunching fields to the micropulses as they traverse from the RFQ output to the first accelerating gap in the RGDTL.

The buncher length C_L is a one-beta-lambda drift since the buncher does not on the average accelerate the beam. This is followed by another one-beta-lambda drift (4.68 cm) to the center plane of the upstream end wall on the RGDTL.

On the upstream end, the buncher interfaces directly with the RFQ and is shaped to provide the inductance and capacitance necessary to tune the ends of the RFQ vanes. On the downstream end, the buncher provides the upstream end wall, half cup, and focusing quadrupole for the RGDTL.

The buncher carries its own slug tuner, rf drive loop and pumpout port. Its nominal operating point is at an accelerating field of 2.75 MV/m, peak surface field of 19 MV/m, and peak power of 15 kW.



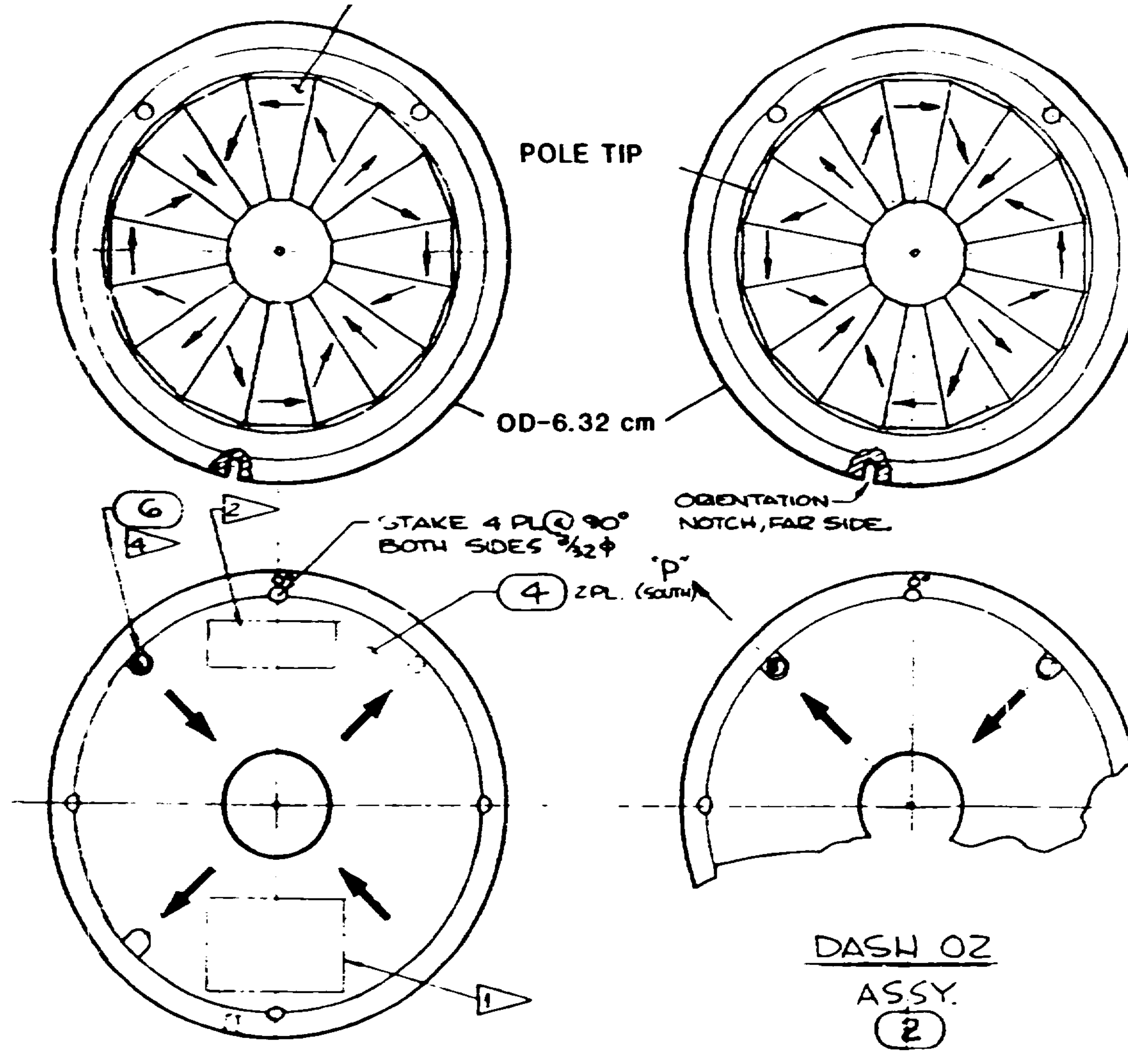
GTA BUNCHER CAVITY

7. 16 SEGMENT RARE EARTH QUADRUPOLES

These quadrupoles are being used in the GTA-1 drift tube bodies. The 16 wedge-shaped segments are magnetized rare earth materials. To meet the needs of GTA-1, i.e., focusing gradient for a given bore and effective length, the material of choice is Neodymium Iron ($Nd_2Fe_{14}B$), which has a residual induction (Br) of about 11 KGauss as opposed to 9.3 KG for samarium cobalt ($SmCo_5$). Radiation resistance of NdFe is lower than $SmCo_5$ but still adequate to meet the needs of GTA.

The above design utilizes keystoned segments for mechanical rigidity. The segments have their easy axes oriented as shown in the top two figures for alternate focusing planes. Other experimental designs, intended for the first high-power test of the split quad concept will use adjustable or shimmable segments made possible by captive screws in the yoke.

Epoxy potting for hard vacuum service is possible using high vacuum-grade epoxies such as DOW DER 332 with Jeffamine T403 as a curing agent. Vacuum bakeout can be accomplished at 77°C while thermally setting the quadrupole.



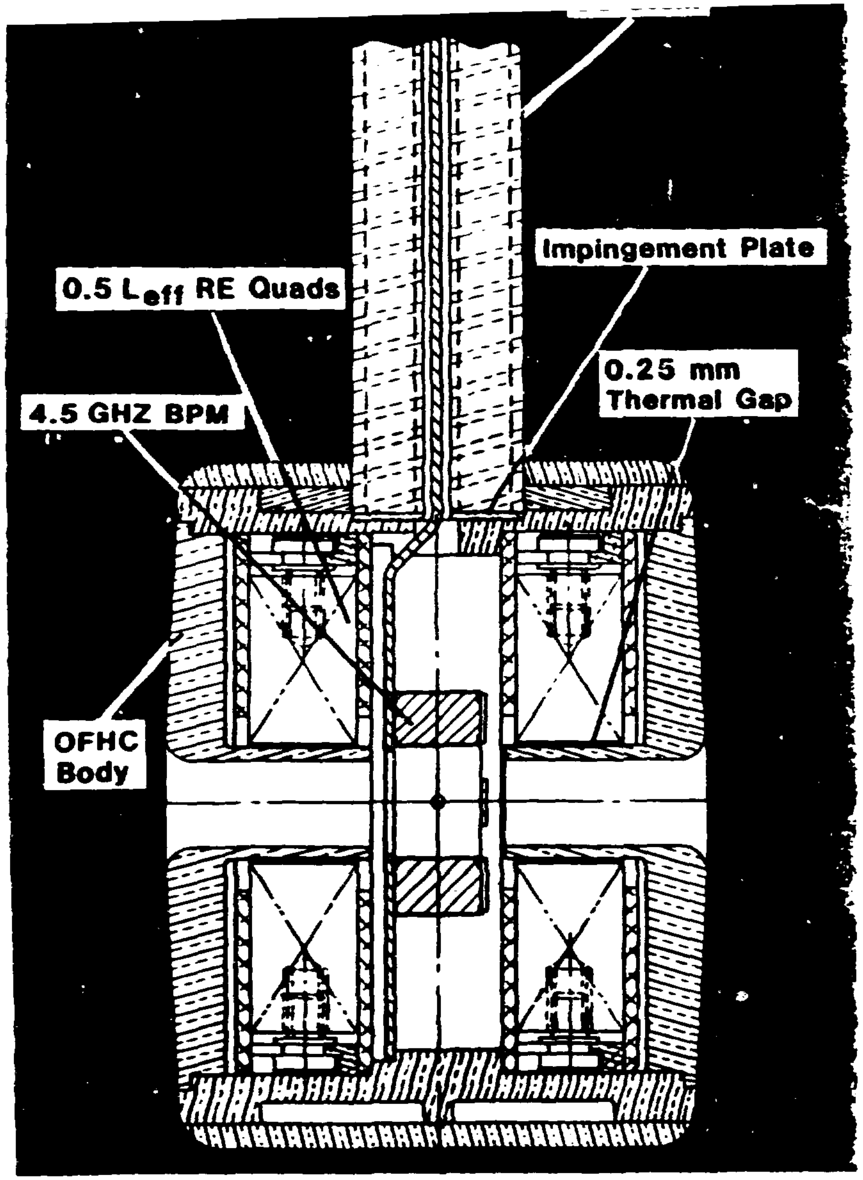
16 SEGMENT RARE EARTH QUADRUPOLE

8. Split-quad Concept

By separating the quadrupole into a split singlet, it is possible to provide access for a beam diagnostic probe. This probe uses stripline techniques and high frequency response to provide not only beam position information, but micropulse information such as profile and energy as well. The probe receives signals for the micropulse structure of the beam through a gap provided in the drift tube boretube.

The boretube gap prevents thermal expansion from distorting the drift tube body and detuning the cell. The gap merely closes slightly under intense beam loss. The quadrupoles do not reference by clamping on the boretube but are instead separated by a thermal gap of about 0.25 mm all around. The quadrupoles are referenced to the datum surface formed by the precision bore of the drift tube body into which the yoke slips.

A full-length azimuthal cooling jacket protects both the probe and the quadrupole from rf power dissipation on the outer radius of the drift tube.



6.7 MeV INSTRUMENTED DRIFT TUBE

9. *Thermal Analysis*

Thermal analysis done on the split quad, split bore drift tube concept shows a high capability for operation at elevated duty factor and significant beam loss heating of the boretube.

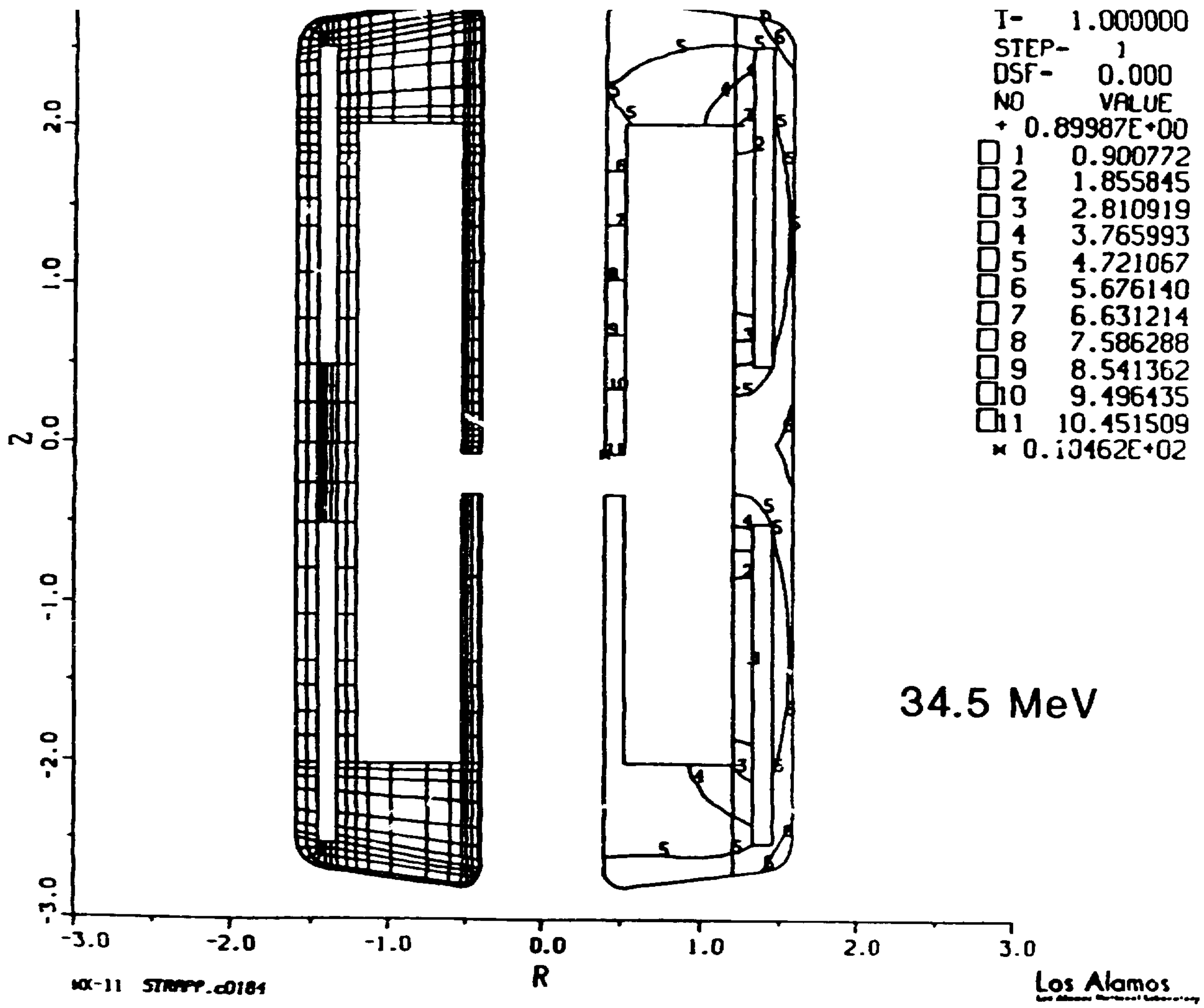
Examples of analyses on a 34.5 MeV drift tube are shown. The following thermal loading was assumed:

rf power deposited = 19 kW peak

Beam loss at 30 μA/m = 108 W peak

The rf power is mostly deposited on the outer radius outside the cooling jacket. The beam loss power is concentrated in a 0.5-cm band in the central region of the boretube.

At 0.1% duty factor, negligible temperature rise will develop along the boretube. At 5% duty shown, a modest ΔT of 6°C exists. The thermal limit of this drift tube is estimated to be reached at 77% duty factor with standard beam loss in which case ΔT = 90° C. At 100% duty with no beam loss, the maximum temperature rise at the outside corners of the DT is almost 69° C. The advantages in using solid copper are clear. In addition, such designs as these permit consideration of "burst-mode" operation, i.e. no cooling for a number of pulses.



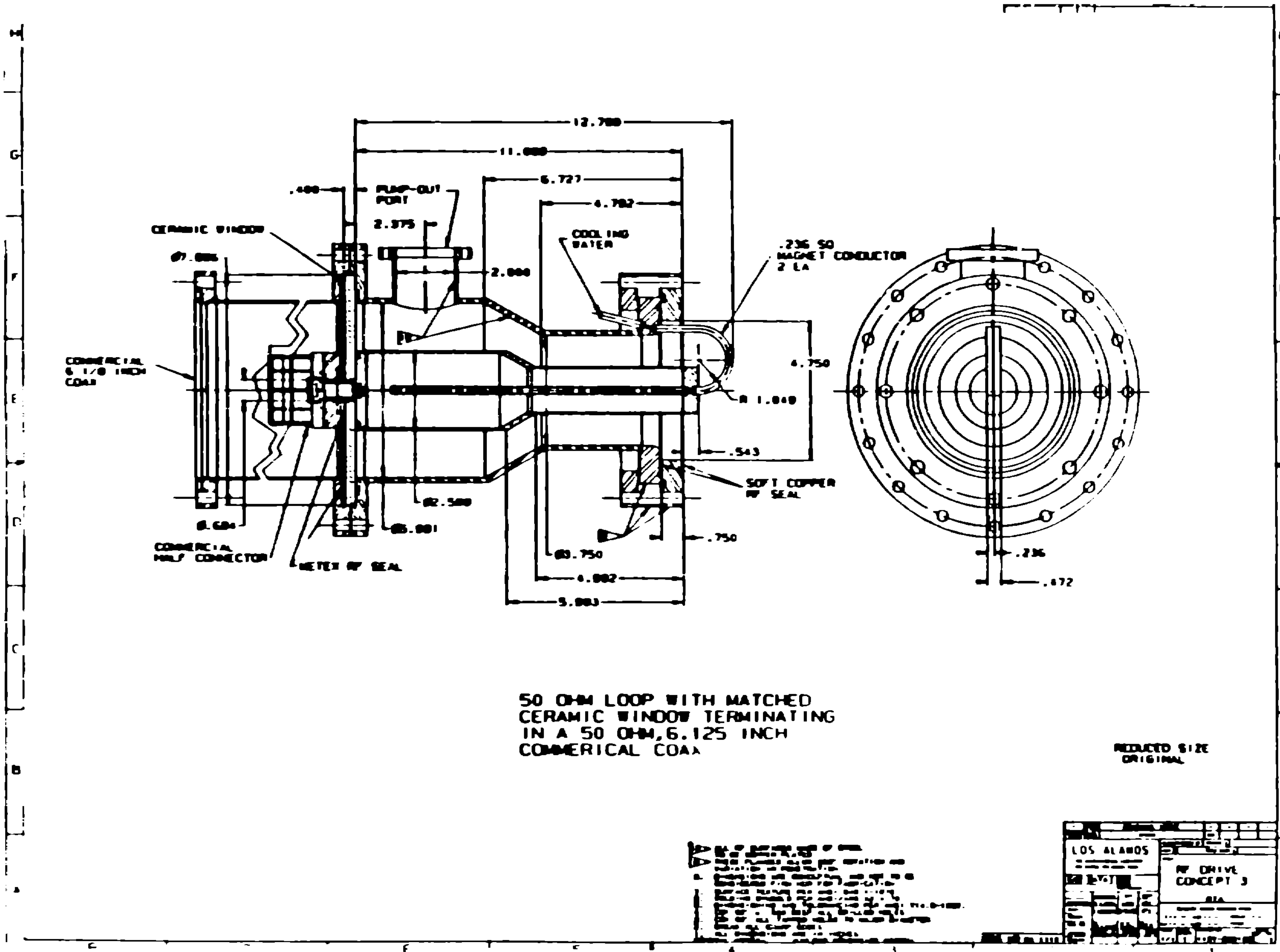
THERMAL STUDY OF 34.5 MeV GTA DRIFT TUBE

10. 500 kW RF Drive Loop

An important peripheral component in the DTL design, a flat window rf drive loop is presently being fabricated for high power testing. Shown above is a 500kW design which couples directly to 6-1/8" commercial power coax. The 6-1/8" coax in turn will couple neatly to the solid state power amplifiers under development, or to the BMEWS klystrons through waveguide/coax power transitions.

The experimental drive loop is matched to 50-ohm characteristic impedance, and utilizes a high-purity alumina window. As many as four of these loops are required to drive each high powered tank in the GTA-1 DTL.

A one megawatt drive loop is also under consideration. It might be used to minimize the transmission line congestion problem in GTA-1.



50 OHM LOOP WITH MATCHED CERAMIC WINDOW TERMINATING IN A 50 OHM, 6.125 INCH COMMERICAL COAX

9004-VG-6166

11. <u>Taut Wire Alignment</u>

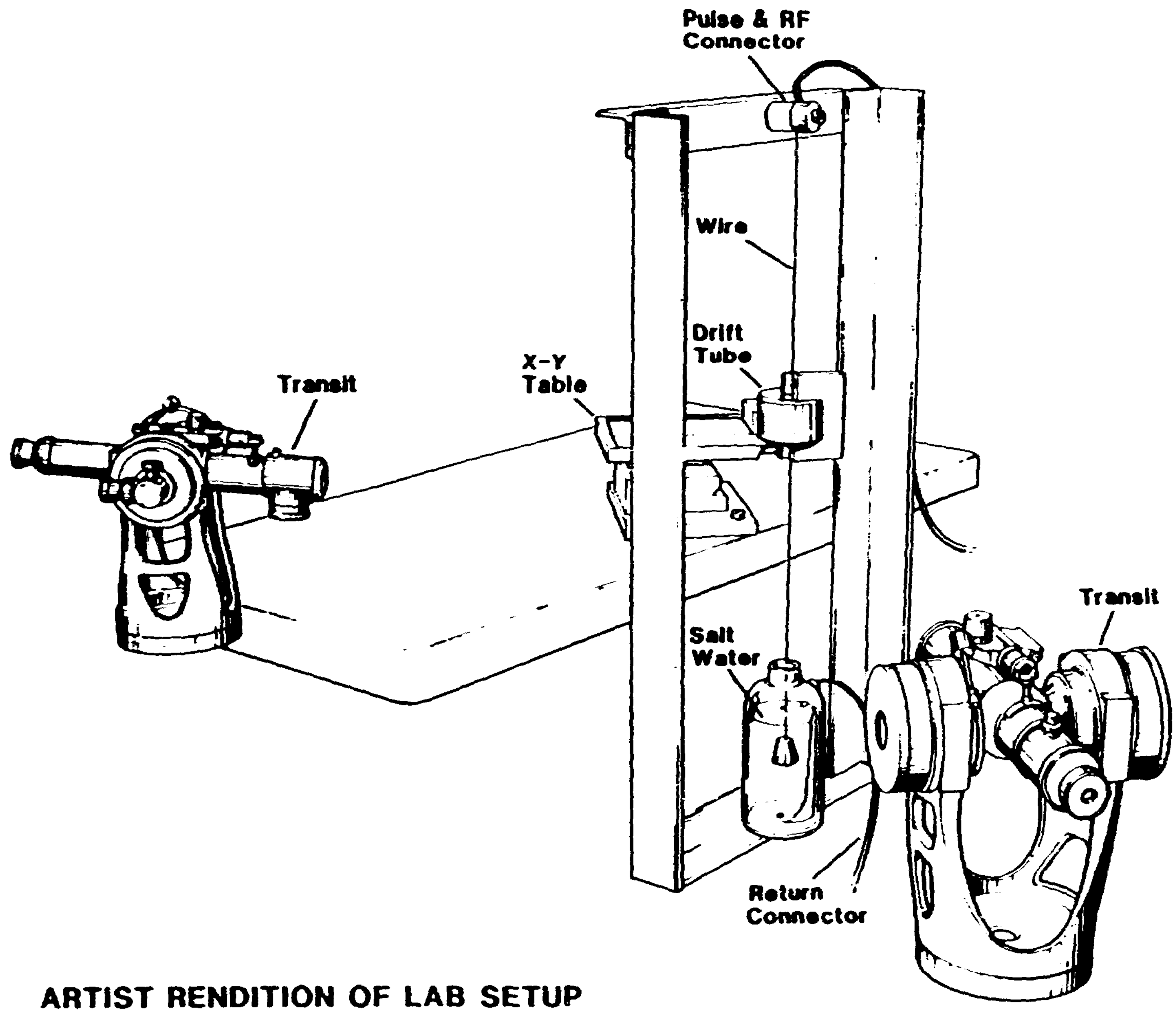
The LBL technique developed by Robert Main for alignment of drift tubes using a current-carrying taut wire has been resurrected at Los Alamos for determining the magnetic centers of the new, high-powered permanent magnet drift tubes.

The original technique used a horizontal tungsten wire tautly strung through the drift tubes of an assembled linac tank. As each electromagnetic quad was switched on, current pulses delivered down the wire caused it to recoil if it was off the magnetic center. The new application of the technique cannot be applied in this way since the quads are permanent magnets.

Instead, the wire is fed vertically through each single drift tube before installation and pulsed to determine the magnetic center relative to the drift tube o.d. These data are then fed in the alignment scheme of the machine to provide offsets for the drift tubes.

Sensitivity of the technique is ±0.003 mm, and drift tube alignment of ±0.05 mm has been achieved.

The GTA DTL requirement for mechanical alignment is a maximum of ±0.125 mm but we will attempt to approach ±0.05 mm.



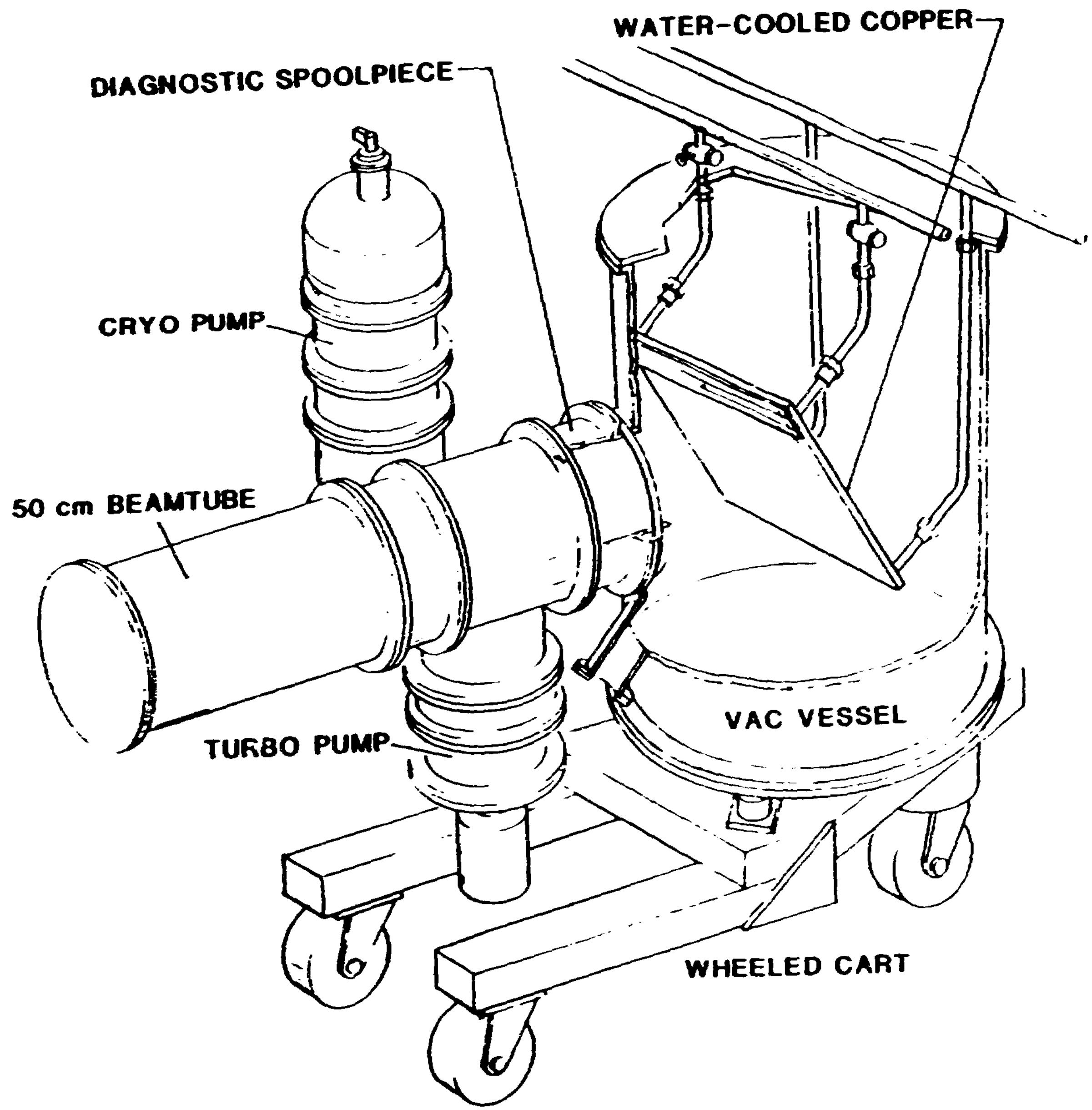
ARTIST RENDITION OF LAB SETUP

#8

12. GTA-1 H^- Beamstop

The mobile beamstop for the GTA-1 H^- beam is shown. This unit is used in commissioning the linac and during tuneup, when the 180° bend magnet is switched off. The beamstop utilizes the central plate from FMII, a water-cooled copper assembly capable of dissipating 500 w/cm^2 from a low energy beam. At 50 MeV, protons produce much neutron activation so the plate is sheathed in graphite to prevent the protons from striking metal. The power density is reduced to 20 w/cm^2 to allow mechanical attachment of the graphite tiles.

The beamstop can be wheeled up to any of the DTL tanks as they are serially installed for on-line checkout.

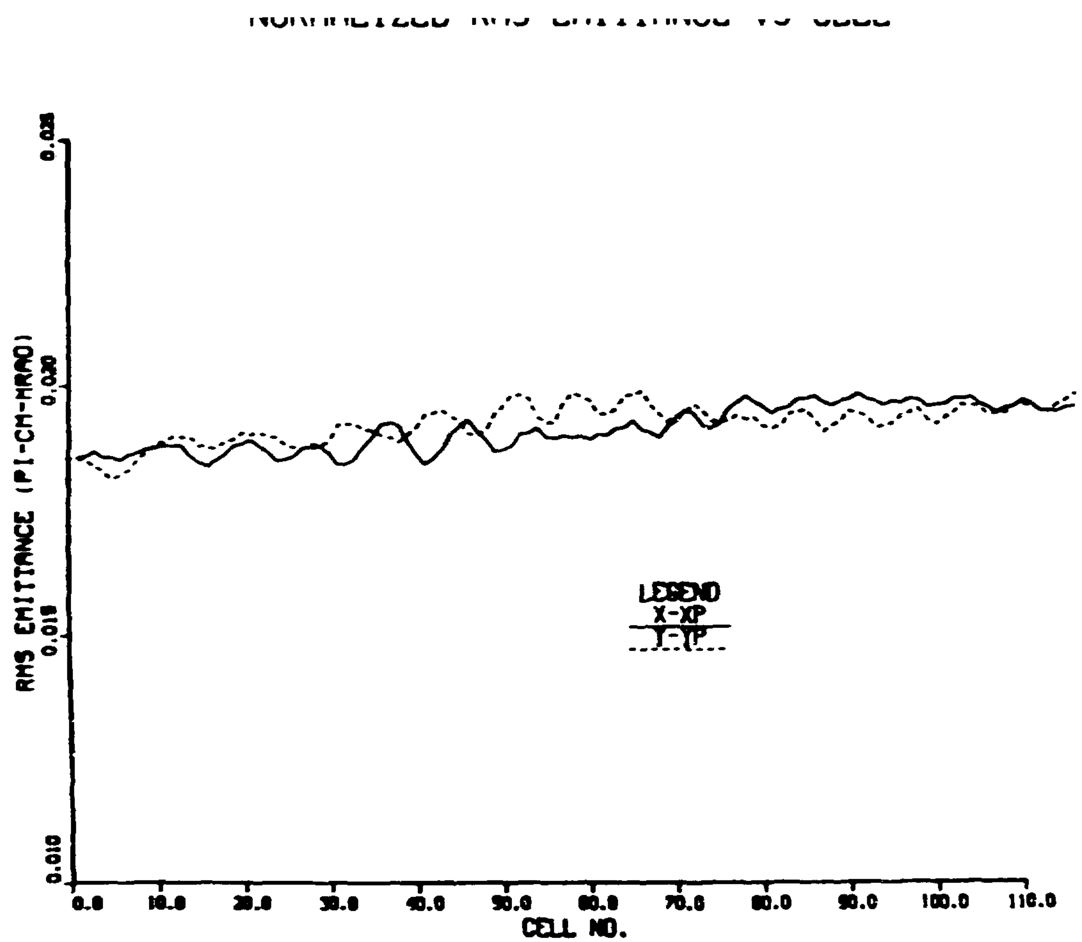


GTA-1 H MOBILE BEAMSTOP (5KW)

13. Beam Dynamics Through the GTA-1 DTL

The above figure shows the emittance growth through the GTA-1 DTL. The results of a PARMTEQ run through the GTA 1 RFQ is used as input for a PARMILA run through the DTL. The DTL emittance growth with an input of 100 mA is about 8% and does not exceed 0.02 π cm•mrad at 50 MeV. Emittance growth in the last three tanks is essentially zero.

The computation shown is the final run made on the DTL with split singlet quadrupoles and shows that such an arrangement produced only slightly more emittance growth than an ideal singlet system.



Normalized rms emittance for X-X' and Y-Y' phase planes.
GTA-1 DTL with 100 mA beams.

III.D. BEAM MAGNETIC OPTICS (BMO)

(Matching Sections, 180° Bend, Telescope & Steering)

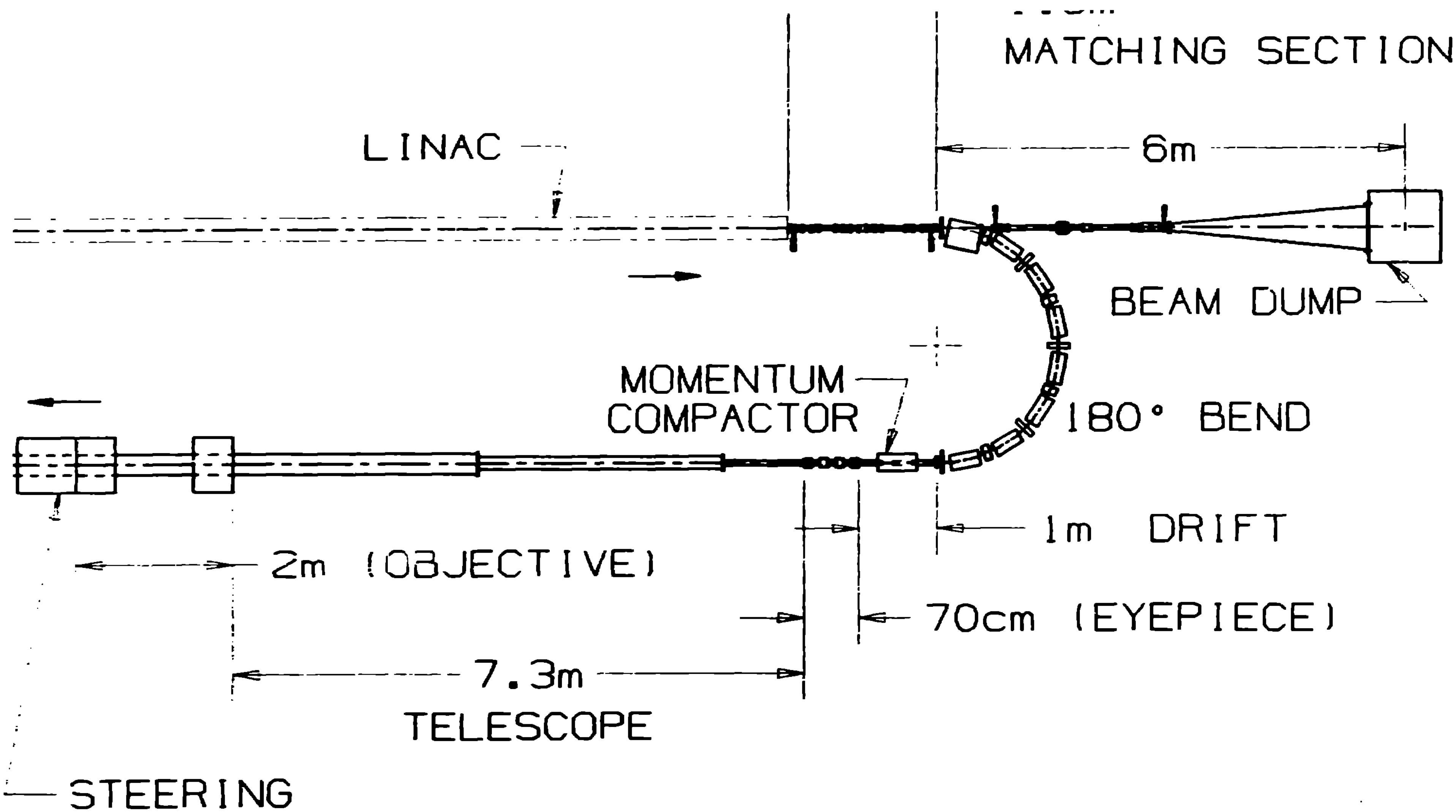
III.D. BEAM MAGNETIC OPTICS

- Develop magnetic systems with small aberrations to maintain low emittance growth
- Initial aberration studies of a prototype telescope at Argonne National Lab in FY'87
- Design magnets for light weight
- Develop high-accuracy beam diagnostics to measure beam performance in the transport system

GTA MAGNETIC OPTICS

	GTA-1
180° Bend	
Number of Bends	1
Dipole Magnets	7 Permanent 1 Electromagnet
Quadrupole Magnets	9
Bend Diameter	3.0 m
Clear Aperture	3 cm
Beam Radius	1 mm rms

	GTA-1
Expanding Telescope	
Eyepiece	Quadrupole Doublet 3 cm Aperture Variable Permanent Magnet
Objective	Quadrupole Doublet 30 cm Aperture Permanent Magnet Beam Radius 3.0 cm rms
Telescope Length	10 m
Steering Magnets	1 Cosine Wound Electromagnet Steers ± 0.5° in 1 second



GTA PHASE 1
OUTPUT OPTICS LAYOUT

SUMMARY

180° BEND

- DOMINATED BY SPACE CHARGE BUT CAN BE SOLVED BY QUADRUPOLE COMPENSATION.

TELESCOPE

- DOMINATED BY ABERRATIONS BUT CAN BE BALANCED AGAINST FIRST ORDER AND REDUCED WITH OCTUPOLES.

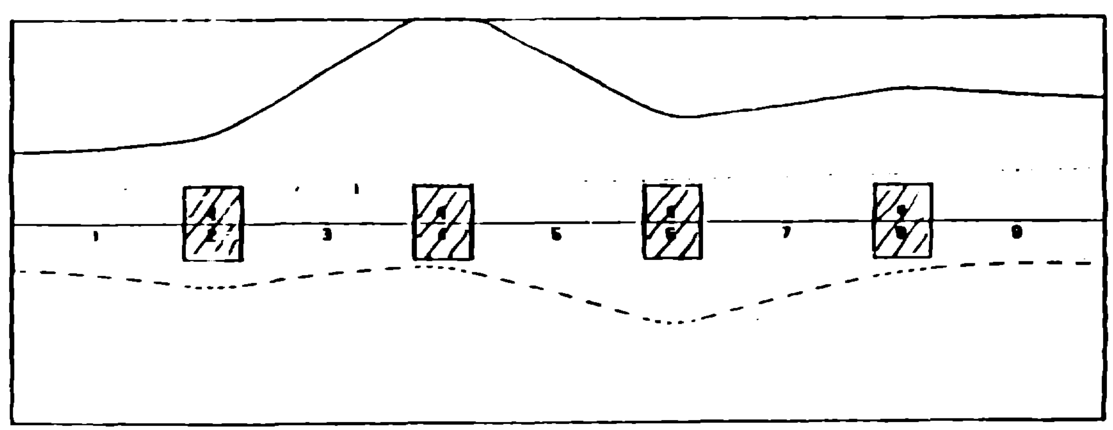
STEERING

- DOMINATED BY CHROMATISM BUT CAN BE MADE ACHROMATIC AND SENSITIVITY REDUCED BY DEBUNCHING.

GTA-1 MATCHING SECTION

4 Quads Variable

3 cm Bore 10 cm Long
11 to 34 T/m Nominal Fields
(.16 to .51 T Pole Tip Field)



180^{O} BEND

– The solution is difficult to achieve even in simulation.

– The design code is being upgraded to ease this.

– The solution depends on beam current,
have to design for 20 mA to 100 mA range.

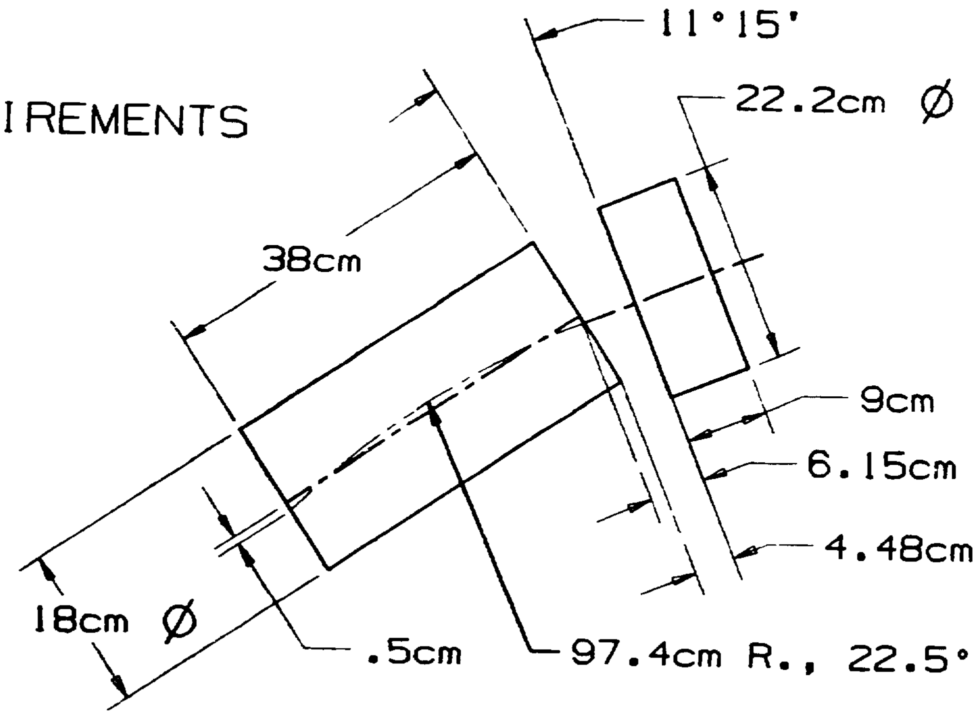
– Variable permanent quadrupoles are required.

– The bend will be difficult to tune in practise. Good diagnostics on position and profile are required.

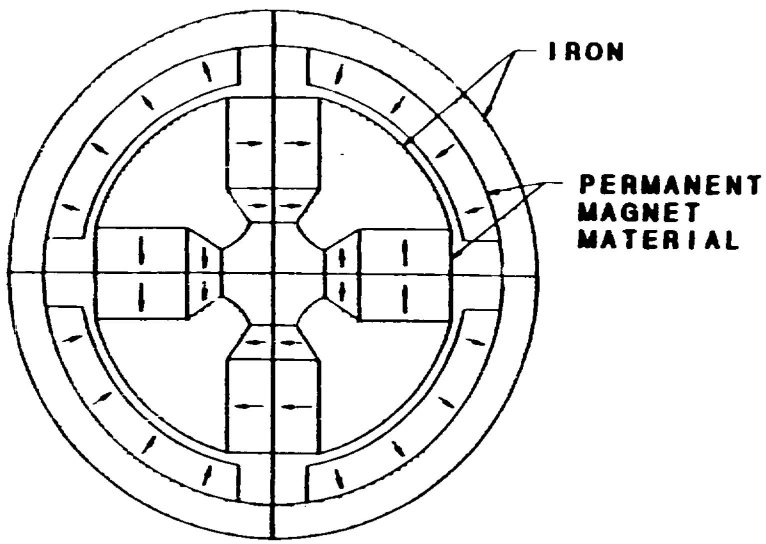
QUADS: 5cm BORE, 9cm LONG, VARIABLE
5 FOCUSING: 42.2 TO 33.7 T/M ALONG BEND
FOR 100ma, 28.7 T/M FOR ZERC CURRENT
4 DEFOCUSING: -31.1 TO -25.5 T/M ALONG BEND
FOR 100ma, -25.1 T/M FOR ZERO CURRENT

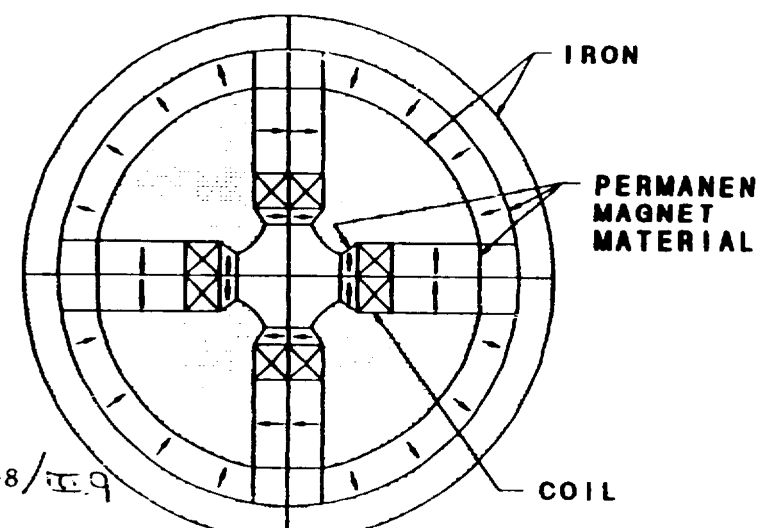
DIPOLES: 38cm LONG, 1.06 TESLA
RING DIPOLE FOR BASELINE DESIGN, 5cm BORE

FIELD QUALITY REQUIREMENTS
NOT SEVERE
-SPACE CHARGE
MOST IMPORTANT



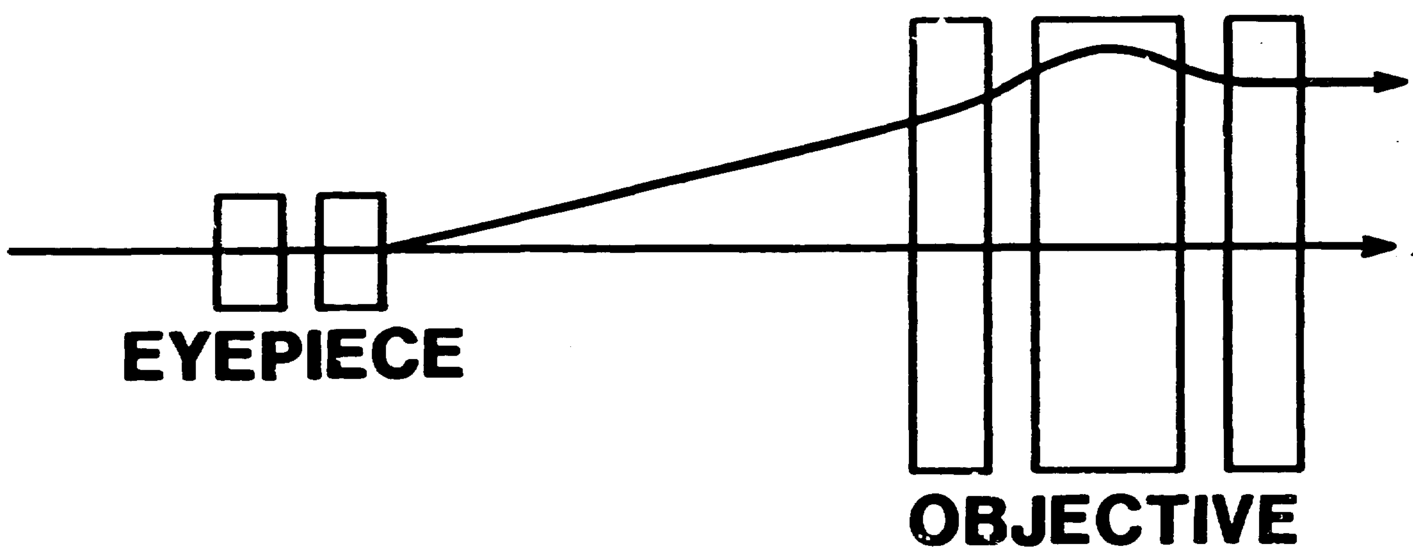
VARIABLE QUADS

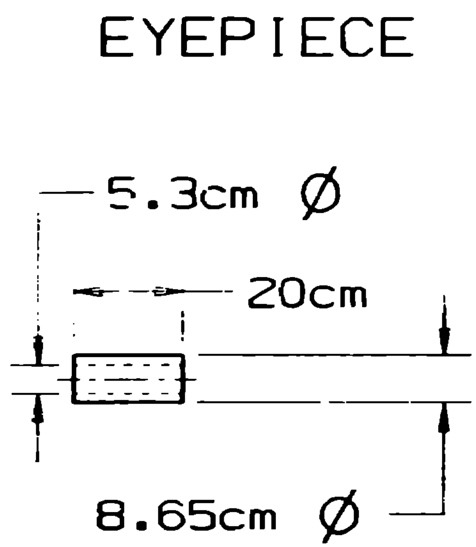




TELESCOPE

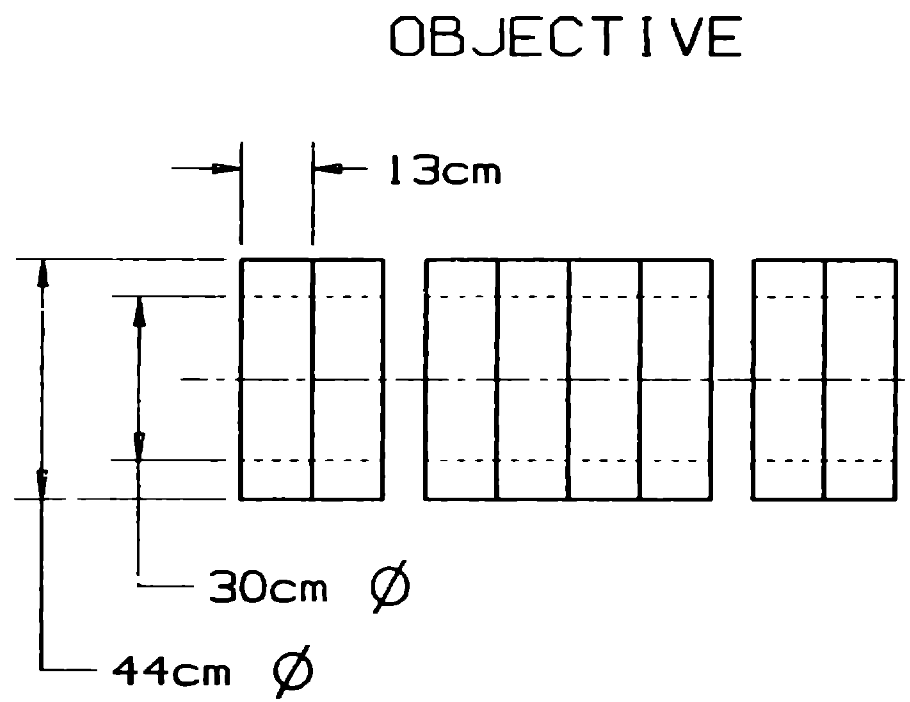
- THE BEAM IS INCREASED IN SIZE 25 TIMES
- SPACE CHARGE FORCES VANISH
- ABERRATIONS REMAIN





INT. GRADIENT:
.658 T/M

1% SEXTUPOLE
5% OCTUPOLE



GRADIENT IN EACH SECTION
THE SAME - 1.92 T/M

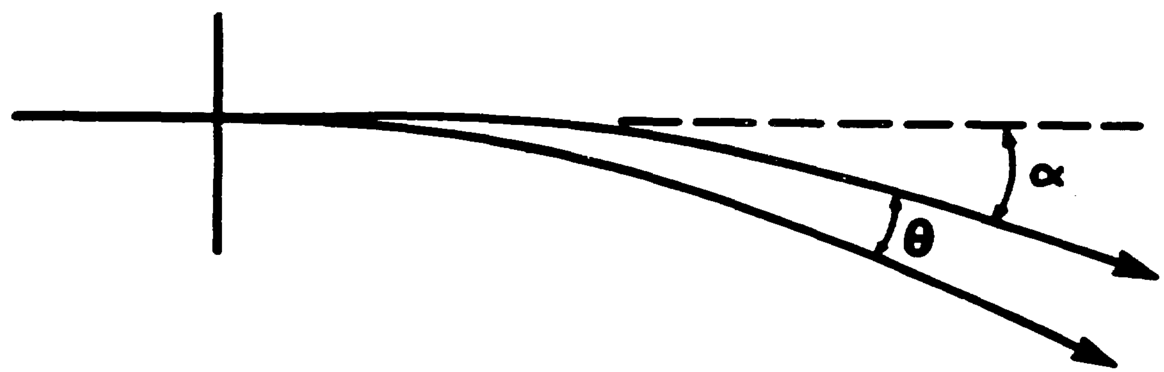
.461 T .883 T .461 T

.1% SEXTUPOLE
.5% OCTUPOLE
1.5% OTHERS

STEERING

HERE THE CHROMATIC EFFECTS DOMINATE FOR A SIMPLE DIPOLE STEERER THERE IS A LINEAR TERM

$$\theta = \sin\alpha \cdot \delta$$



THIS CAN BE VERY LARGE

FOR $\alpha = 0.5°$ $\delta = 0.003$

$\theta = 26\ \mu$ RADIANS !

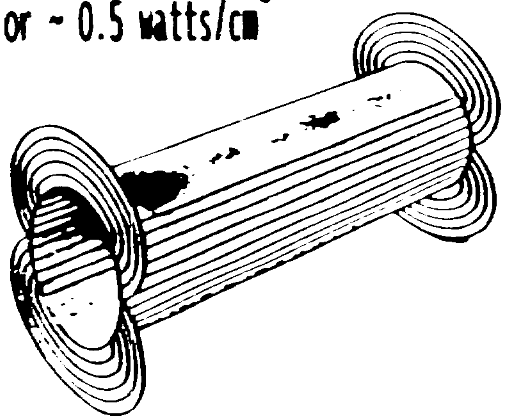
- Iron Shell (x 2 Field)
- $\pm$ 0.5° Deflection
- 30 cm Bore
- 0.25 mm Conductor x 2
- 200 Turns/m
- 90 Gauss - m
- 0.5 m Long, e.g.

$\downarrow$

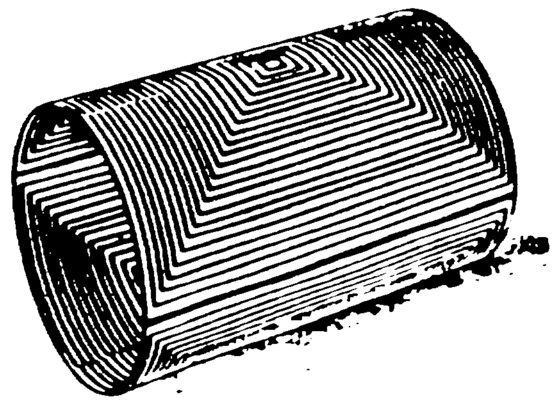
- 22 A

- 2.4 kW or ~ 0.5 watts/cm^2

$$J_z z = A \cos \theta .$$



Dipole with plane ends.



Lambertson dipole.

4 Windings = Quadrupole
6 Windings = Sextupole
8 Windings = Octupole

BUNCHER CAVITY (MOMENTUM COMPACTOR)

pair of side coupled cavities
shunt impedence 40 MΩ/m
transit time factor ~ 0.9
voltage 890 kV
length 44cm (425 MHz, $\beta\lambda/2$=22cm)
diameter 50cm
power 46 kW CW

Beam loading	2 cavities	4 cavities
induced voltage	1.76 MV	3.5MV
tuning angle	63 °	77°
frequency shift	12 kHz	25 kHz

Emittance term

$$\theta = \frac{\varepsilon_n}{\beta\gamma\, x}$$

Telescope

Chromatic term

$$\theta = \frac{\Delta p}{p}\,\frac{x}{L}$$

Geometric term

$$\theta = k\,\frac{x^3}{L^3}$$

Steerer

Chromatic term

$$\theta = \frac{\Delta p}{p}\,\sin\alpha$$

Field quality term

$$\theta = Q\;\alpha$$

GTA EXPERIMENT

Contributions to divergence: (μradians)

Emittance	Telescope Chromatic	Telescope Geometric	Steerer Chromatic	Steerer Field Quality	Total
20	12	20	26	9	41

Chromatic and quality corrections added to the steerer gives

20	12	20	9	3	32

Balancing the 3rd order aberrations against the first order solution gives

20	12	7	9	3	26

Add energy compactor (debuncher, bucket rotator)

20	4	7	3	3	22

Octupole correction of the geometric aberrations gives

20	4	3	3	3	21

Increasing telescope length to 10 meters gives

20	9	3	9	3	24

Add energy compactor (debuncher, bucket rotator)

20	3	3	3	3	21

GTA-1 Mod 1: Debunched to 0.001 dP/P; 10m x 0.4m telescope; 0.5 deg steering

40	cm	GTA-1 telescope bore
60	cm-μr	Laboratory emittance at 50 MeV (20 cm-μr normalized)
1000	cm	10m GTA-1 telescope length
0.001	dP/P	Debunched to 100 KeV energy spread
312	radians	Aperture aberration coefficient for f/25 telescope (1000/40)
0.0087	sin(0.5deg)	Maximum steering angle of 0.5 degrees
0.001	radians	Steering magnet field quality term
0.333	correction factor	Balance 1st and 3rd order aberrations in telescope, and trim steering

		TELESCOPE CONTRIBUTION		STEERING CONTRIBUTION				
x(0)	Ø-emit	Ø-chromat	Ø-aperture	Ø-chromat	Ø-quality	x(0)	Ø-telescope	Ø-total
2.0	30.0	2.0	0.8	2.9	2.9	2.0	30.1	30.4
2.5	24.0	2.5	1.6	2.9	2.9	2.5	24.2	24.5
3.0	20.0	3.0	2.8	2.9	2.9	3.0	20.4	20.8
3.5	17.1	3.5	4.5	2.9	2.9	3.5	18.1	18.5
4.0	15.0	4.0	6.6	2.9	2.9	4.0	16.9	17.4
4.5	13.3	4.5	9.5	2.9	2.9	4.5	17.0	17.4
5.0	12.0	5.0	13.0	2.9	2.9	5.0	18.4	18.8
5.5	10.9	5.5	17.3	2.9	2.9	5.5	21.2	21.6

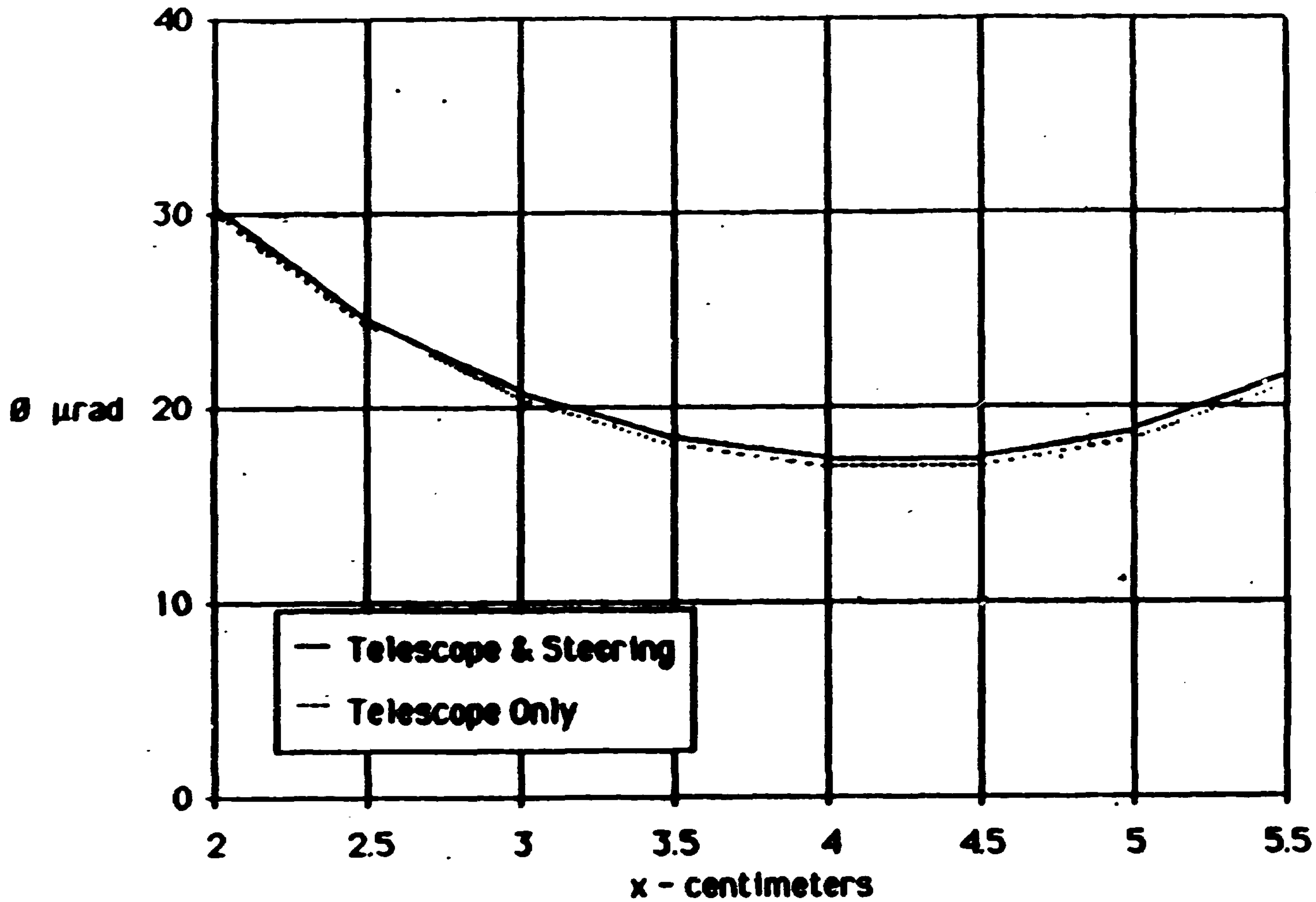
Ø-emit = emittance/x

Telescope Ø-chromatic = dP/P*(x/L)

Telescope Ø-aperture = (312)*(x/L)^3*f (Triplet, linearly scaled in all dimensions)

Steering Ø-chromatic = dP/P*sinA*f

Steering Ø-quality = 0.001*A*f


40
30
Ø μrad
20
10
0
2
2.5
3
3.5
4
4.5
5
5.5
x - centimeters
Telescope & Steering
Telescope Only

BASELINE DESIGNS:

ARGONNE

- 7.5 meter telescope, triplet objective
- debunched to 0.001 $\Delta p/p$
- 1st and third order aberrations balanced
- octupole correction experiment in one plane
- chromatic and quality corrections on steerer

GTA-1

- 10 meter telescope, doublet objective
- debunched to 0.001 $\Delta p/p$
- 1st and third order aberrations balanced
- octupole correction in two planes
- chromatic and quality corrections on steerer

NPB
MAGNETIC OPTICS

GENERAL CONSIDERATIONS

- VACUUM MATERIAL – STAINLESS THROUGHOUT FOR ARGONNE, ALUMINUM FOR GTA-1
- VACUUM – 10^{-6} TORR
- ASA COMPATIBLE FLANGES AT VACUUM SYSTEM INTERFACES, SPECIALS IN THE BEND
- TURBOPUMP, TURBO-BACKUP PUMP, AND CRYOPUMP

MAGNETS

- PERMANENT MAGNETS, FIXED AND VARIABLE FIELDS
- DESIGN FOR COMPACTNESS AND LIGHTWEIGHT

MAGNET MOUNTING

- COMMERCIAL, ADJUSTABLE PRECISION MOUNTS WHEREVER PRACTICAL
- ADAPTATION OF CONCEPTS PREVIOUSLY DEVELOPED FOR MIRROR POSITIONERS
- MANUAL ADJUSTMENT, WITH LOCKING FEATURES
- MOTORIZING CAPABILITY FOR ALL POTENTIALLY SENSITIVE DOF's
- PROVIDE UNCOUPLED MOTION OF INDIVIDUAL DOF's WHEREVER PRACTICAL

III.E. NEUTRALIZER

III.E NEUTRALIZER

1. Baseline Neutralizer Design

The options considered for neutralizing the particle beam were: gas cells, both static and dynamic; solids, including thin foils, soap films, dust particles, and vapor or liquid droplets; laser photodetachment; plasmas; charged particles beams; and electro-magnetic fields. The baseline design selected was an axial flow gas cell. This selection was made because the mature technology of the gas cell suggested it would be the only way to assure a neutralizer could be designed and fabricated in time to meet the program schedule.

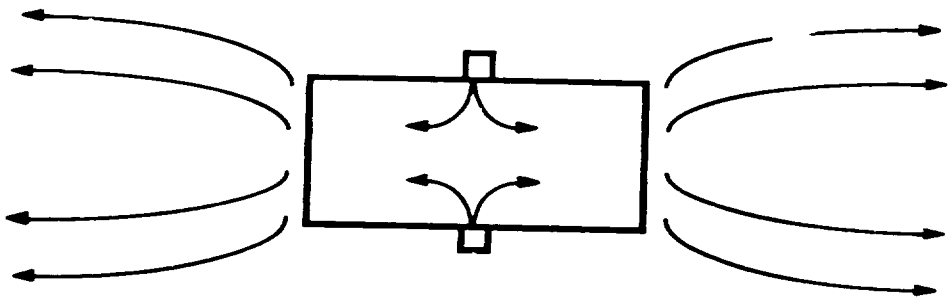
The axial flow gas cell consists of a circular tube into which gas is injected through a series of small orifices drilled around the circumference of the tube at its mid-plane.. The gas is injected from a plenum for equal distribution to the orifices. The injected flow fills the neutralizer tube and flows equally out both ends. It is emphasized that the gas flows equally out of both ends of the neutralizer and is not preferentially forward directed as is done in the BEAR neutralizer or was previously proposed for GTA-1. The reason is, it is just as important to keep gas out of the beam sensing area downstream of the neutralizer as it is to keep gas out of the telescope region upstream.

The charged particle beam from the accelerator passes through the gas on the axis of the tube and is neutralized by coulomb interaction with the gas molecules. This technology is straightforward.

Solid, thin foils have been used in the accelerator field for a number of years and are a very attractive alternative to gas cells. Foil neutralizers have more advantages than gas cells, the greatest being that they do not require the gas injection that destroys the integrity of the vacuum in the system. However, foils the size (diameter) and thickness required for GTA-1 have not been developed yet, so the foil design is being carried as a back-up concept pending development of the proper foil.

BASELINE NEUTRALIZER DESIGN

- BASELINE DESIGN SELECTED FOR THE GTA-1 NEUTRALIZER IS AN AXIAL FLOW GAS CELL CONFIGURATION.



- BACK-UP DESIGN IS A FOIL NEUTRALIZER.

2. Baseline Gas Cell Design Parameter

The design parameters were chosen as a compromise between stripping efficiency, beam divergence, and the amount of gas injected into the system. The stripping efficiency is a function of the target thickness, which is a function of the gas density and the neutralizer length. The beam divergence is a function of the neutralizer length. The amount of gas injected into the system is a function of the gas pressure (density) and the exit bore diameter.

The target thickness was chosen from theoretical considerations as being that which gives maximum stripping efficiency. The 100 cm length and the 2 E-2 torr pressure were chosen as the best compromise between gas density and length to give the required target thickness without making the neutralizer excessively long (beam divergence) or excessively high in pressure (amount of gas injected to system).

The 30 cm diameter is the result of a requirement for a $\pm 1/2°$ beam steering angle from the output optics. This requirement, coupled with the distance of the exit end of the neutralizer from the steering magnet, and the 25 cm beam diameter, resulted in the 30 cm neutralizer diameter to prevent the beam from clipping the walls.

Argon was chosen as the baseline gas. Nitrogen and carbon dioxide are also being considered. Carbon dioxide is of interest because it is more easily condensed than argon or nitrogen and would not require as cold a surface temperature on the cryopanels that will be installed to pump the gas from the system.

The total peak mass flow is the amount of gas that will flow from a 30 cm diameter orifice with an upstream pressure of 2 E-2 torr. This is the rate at which gas would be added to the system if operated continuously. However, to reduce the amount of gas added, the flow will be pulsed at a rate of 3 gas pulses per second with a pulse width of 30 msec per pulse. This results in an average mass flow rate that is approximately 10 times less than the total peak flow, i.e. 0.110 gm/sec.

BASELINE GAS CELL DESIGN PARAMETERS

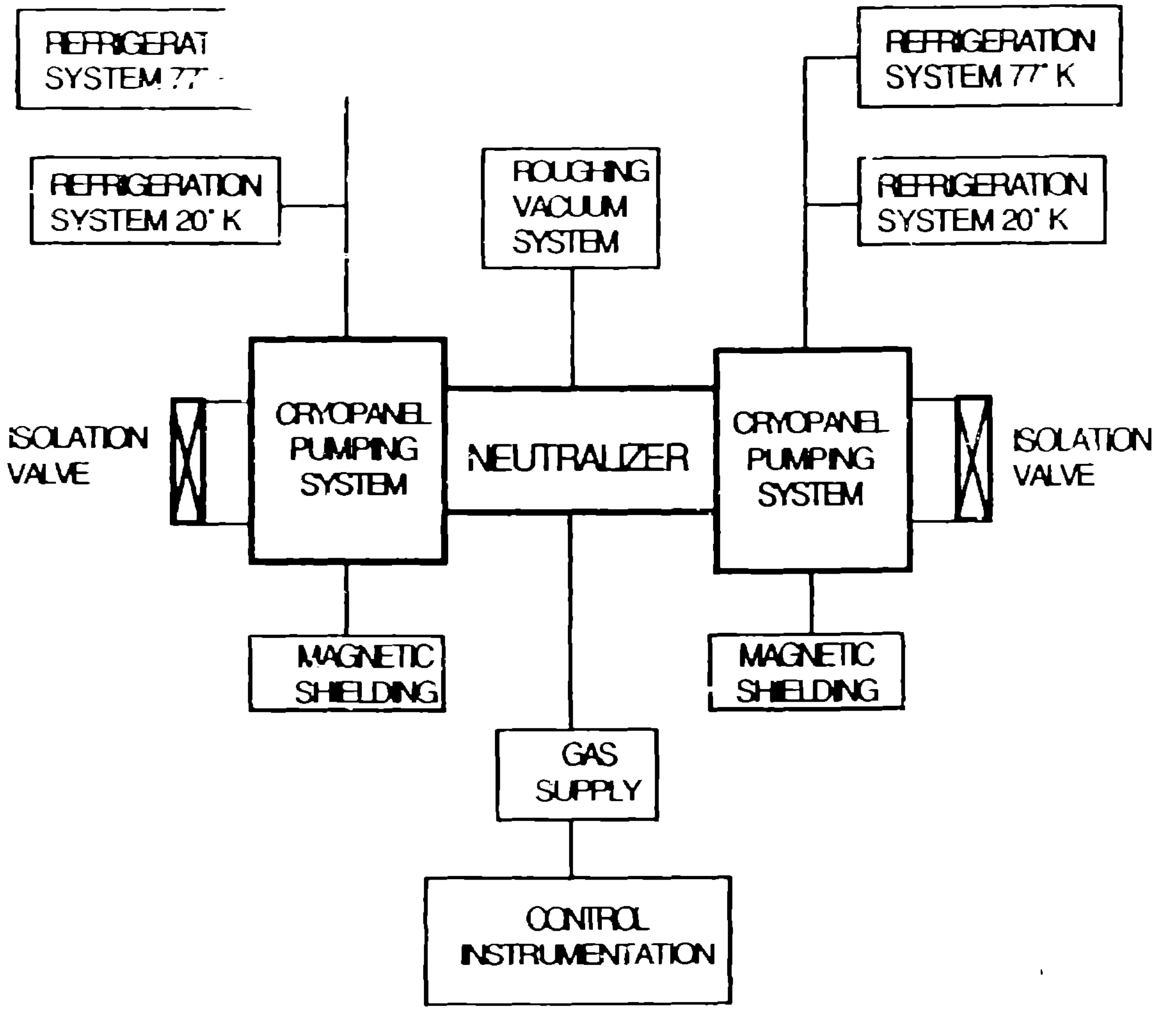
GTA-1
NEUTRALIZER

LENGTH	= 100 cm
DIAMETER	= 30 cm
PRESSURE	= 2×10^{-2} TORR
TEMPERATURE	= 300° K
GAS	= ARGON - BASELINE N_2- BEING EVALUATED CO_2- BEING EVALUATED
TARGET THICKNESS	= 4.5 ug/cm^2
MASS FLOW	= 1.10 gm/sec (Total peak)
REPITITION RATE	= 3 HERTZ
GAS PULSE TIME CONSTANT	= 30 msec
AVERAGE MASS FLOW RATE	= 0.110 gm/sec

3. Neutralizer System Block Diagram

The block diagram shows the various components necessary for the system. The neutralizer tube is shown in the center of the system. The effluent gas ejected from the neutralizer is pumped by a cryopanel pumping system located upstream and downstream of the neutralizer tube. Isolation valves on either end of the system allow it to be isolated from the rest of the system during cryopanel rengeneration. This prevents pressure build-up in the rest of the system. External to the system are the support systems. A roughing vacuum system consisting of a mechanical pump for rough pumping and a turbo pump for faster pumping at low pressures will be used to initially evacuate the system and then to pump off the condensed gases as the cryopanels are regenerated. Refrigeration systems are required to provide coolant to the cryopanels. The gas supply delivers the flow to the neutralizer and the control/instrumentation system monitors and regulates the gas flow. The magnetic shielding is required to prevent the earth's magnetic field from interfering with the beam before it is neutralized.

NEUTRALIZER SYSTEM BLOCK DIAGRAM

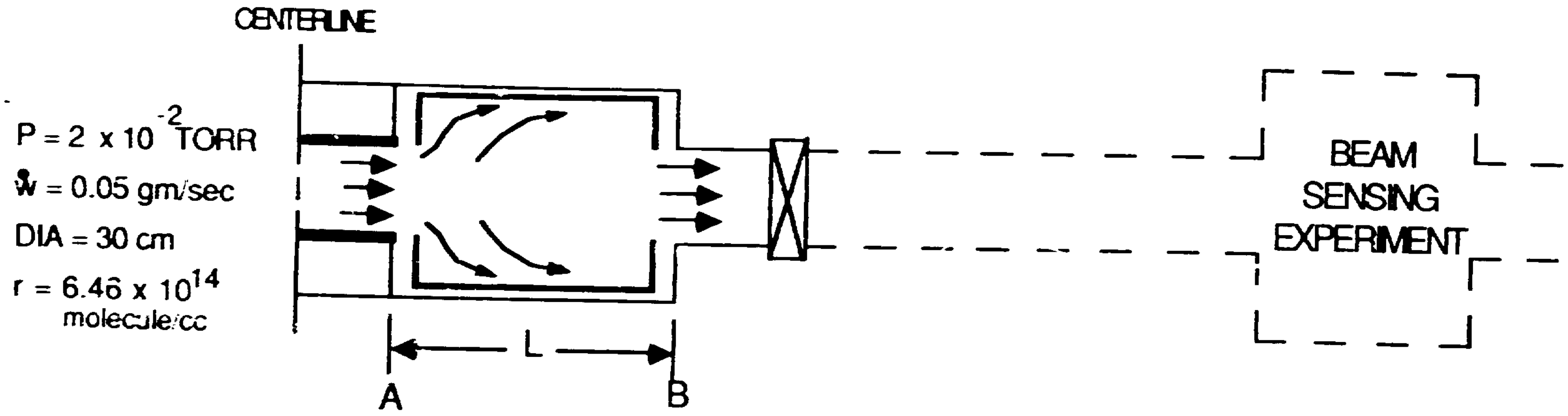


4. Cryopump Length vs Gas Flow

The pressure in the system immediately upstream and downstream of the neutralizer system is a function of the distance from the neutralizer. The gas expands from the neutralizer essentially as a free jet. As the gas expands radially outward it contacts the surface of the cryopanels. If it is assumed that each gas molecule that contacts the cryosurface sticks to the surface and is lost from the gas flow, then the pressure in the axial direction will decrease as the square of the length. The conditions at the exit of the neutralizer cell are shown to the left of the figure. A neutralizer pressure of 2 E-2 torr and an exit diameter of 30 cm result in an effluent mass flow rate of 0.05 gm/sec from each end of the cell. The table shows how the mass flow exiting from the system at point B varies with increasing cryopanel length. For example, the mass flow exiting the system at a distance of 200 cm is only 0.7% of the mass flow ejected from the neutralizer cell. The pumping speeds shown in the table are the pumping speeds that would be required downstream of the isolation valve to maintain the pressures shown. For example, based on the amount of mass flow exiting the system after 200 cm of cryopumping, a pumping speed of 1,600 liters/sec is required to maintain the pressure at 1 E-4 torr, or 16,000 liters/sec is required to maintain 1 E-5 torr.

CRYOPUMP LENGTH vs GAS FLOW

GTA-1
NEUTRALIZER



L	100 cm	150 cm	200 cm
$\dot{w}_B / \dot{w}_A$	3 %	1.1 %	0.7 %
No. DENSITY	6.38×10^{12}	2.79×10^{12}	1.56×10^{12}
LITER/sec @ 10^{-4} TORR	6880	2500	1600
LITER/sec @ 10^{-5} TORR	68,800	25,000	16,000

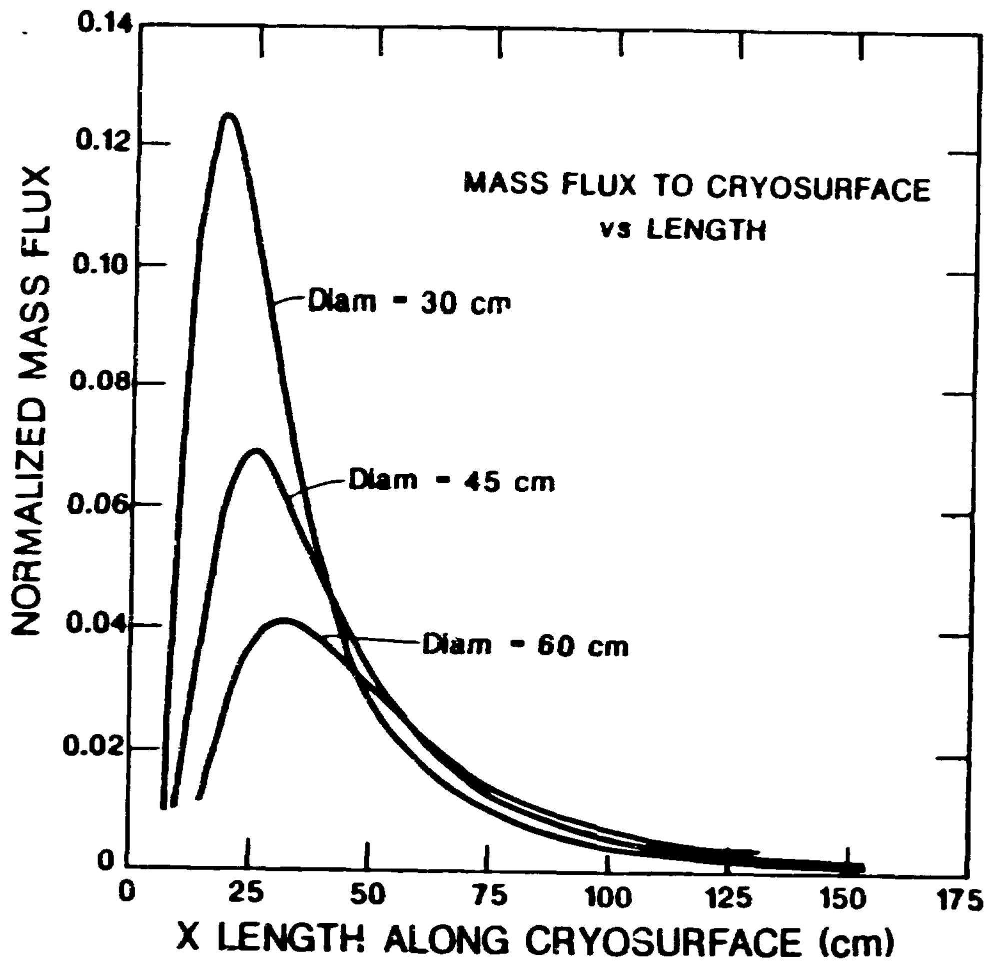
5. Mass Flux To Cryosurface vs Length

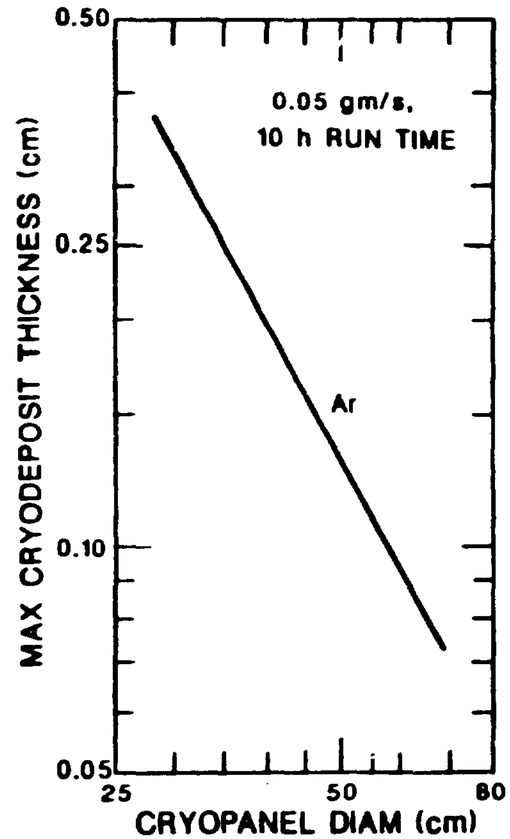
The plot on the left shows the distribution of cryodeposit on the surface of the cryopanels. It is based on analytical predictions of the flow field exiting from the neutralizer. The different curves shown are for different internal diameters of the cryopanel. The smallest cryopanel diameter considered was merely an extension of the neutralizer tube, i.e., 30 cm diameter. The largest considered had a diameter twice that of the neutralizer cell. In all cases, the bulk of the cryodeposit is collected on the surface in the first half of the cryopanel section. The small diameter has the sharpest peak because there is not as much surface area available to distribute the deposit over, and the flow does not have a chance to expand from the neutralizer before striking the surface. Therefore, the bulk of the flow is deposited in the first quarter of the cryosection. As the diameter increases, the surface area increases and the flow expands more. This results in a more even distribution of the deposit and a slower build-up rate.

The plot on the right shows how the maximum deposit thickness varies with cryopanel diameter. For example, after 10 hours of operation at an average mass flow rate of 0.05 gm/sec, a 60 cm diameter cryopanel has a deposit thickness of approximately 0.1 cm at the point of maximum build-up. If it is assumed that the maximum deposit thickness allowed before regeneration is 1 cm, then a 60 cm diameter cryopanel could be operated for approximately 100 hours at an average mass flow rate of 0.05 gm/sec before requiring regeneration. This means the system need only be regenerated once a week.

MASS FLUX TO CRYOSURFACE

GTA-1
NEUTRALIZER





6. Cryopump Refrigeration Thermal Loads

The cryopanel section will be built as three concentric cylinders. The inner cylinder, operating at a nominal 20°K, pumps the effluent gas. The outer cylinder is the vacuum housing and will essentially be at room temperature (300°K). The intermediate cylinder, operating at a nominal 77°K, is a thermal radiation shield to reduce heat gain to the 20°K surface from the vacuum housing. Determination of the thermal loading on the cryosurfaces includes both the loading from gas condensation and the loading from thermal radiation from the surrounding surfaces.

The 20°K surface removes gas from the system by condensing it to a solid. The energy removed from the gas in condensing it goes into the cryosurface and must be removed. The calculated thermal load caused by gas condensation is 18 watts.

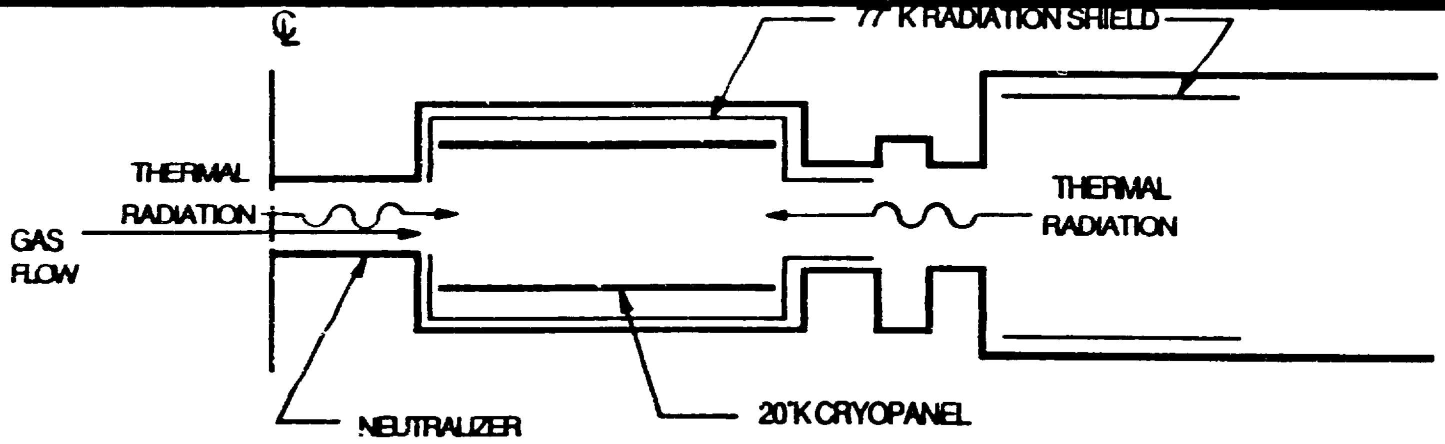
The 20°K cryopanel receives thermal radiation from the neutralizer cell on the upstream end and from the exit tube on the downstream end. If the neutralizer cell and the exit tube are both operated at 300° K, the thermal radiation load on the 20°K surface is 36 watts. When this is added to the load from gas condensation, the total thermal load on the 20°K surface is 54 watts per cryopanel (or a total of 108 watts for both cryopanels).

The radiation loading on the 20°K surface can be reduced considerably by extending the thermal radiation shield in both directions, i.e., extending it to cover the neutralizer cell on the upstream end, and extending it past the end of the 20°K surface on the downstream end. The neutralizer cell can now be operated at a lower temperature by allowing it to radiate to the 77°K shield. The surrounding surfaces that the 20°K surface "sees" are now operating at colder temperatures and the thermal radiation contribution from these surfaces is greatly reduced. If the neutralizer cell is controlled to operate at 150°K and the cryopump exit has a 77°K shield, the thermal load from radiation is now 14 watts, for a total thermal load on the 20°K surfaces of 32 watts.

Thermal loading on the 77°K surface comes from radiation from the vacuum housing walls and from the neutralizer cell. The total calculated thermal load on the 77°K surface is 140 watts per end, or a total of 280 watts.

CRYOPUMP REFRIGERATION THERMAL LOADS

GTA-1
NEUTRALIZER



THERMAL LOAD FROM GAS CONDENSATION (0.05 gm/sec ARGON FLOW)	= 18 watts
RADIATION FROM NEUTRALIZER (300° K)	= 10 watts
RADIATION FROM CRYOPUMP EXIT (300° K)	= 26 watts
	54 watts
RADIATION FROM NEUTRALIZER (150°K) RADIATION FROM CRYOPUMP EXIT WITH 77° K SHIELD	= 14 watts
THERMAL LOAD FROM GAS CONDENSATION (0.05 gm/sec)	= 18 watts
	32 watts
THERMAL LOAD ON 77 K SHIELD	= 140 watts

7. Cryopump Refrigeration Specifications

The cryopanels and thermal radiation shields will be cooled using standard cryopump refrigeration heads attached directly to the surfaces. The heads that will be used for the 20°K surface are two-stage heads with a capacity of 15 watts each at 20°K. Six of these heads (three on each cryopanel) will yield a capacity of 90 watts, which offers a 40% margin in capacity to the calculated 64 watts.

The heads for the thermal shields are single-stage heads with a capacity of 100 watts each at 77°K. Two of these heads on each thermal shield will provide a thermal margin of approximately 45 % in shield cooling.

The calculated time to cool the panels from 300°K to 20°K is 10 hours. This is based on the capacity of the refrigeration heads and the thermal mass of the system. This 10 hour time period does not have to be experienced every time the system is regenerated. During regeneration it is necessary only to warm the system to 100°K to drive off the argon gas. This offers a considerable time savings during regeneration. As shown the calculated warm-up time to 100°K is two hours, and the calculated cool-down time to 20°K is two hours.

CRYOPUMP REFRIGERATION SPECIFICATIONS

- REFRIGERATION REQUIREMENT

  - CRYOPANEL LOAD = 64 watts @ 20° K
    6 REFRIGERATION HEADS = 90 watts (40% EXCESS)
    (15 watts each)

  - SHIELD LOAD = 280 watts @ 77° K
    4 REFRIGERATION HEADS = 400 watts (45% EXCESS)
    (100 watts each)

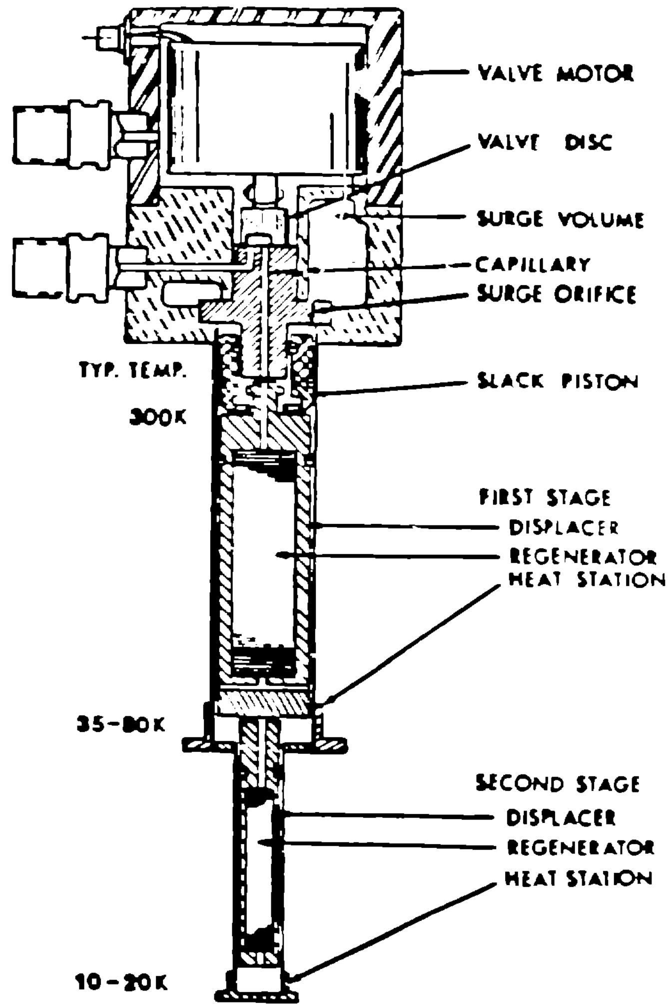
- COOL DOWN TIME = 10 HOURS
  (300°K to 20°K)

- REGENERATION TIME

  - 2 HOURS FROM 20°K to 100°K
  - 2 HOURS FROM 100°K to 20°K

VIEW OF REFRIGERATION HEAD

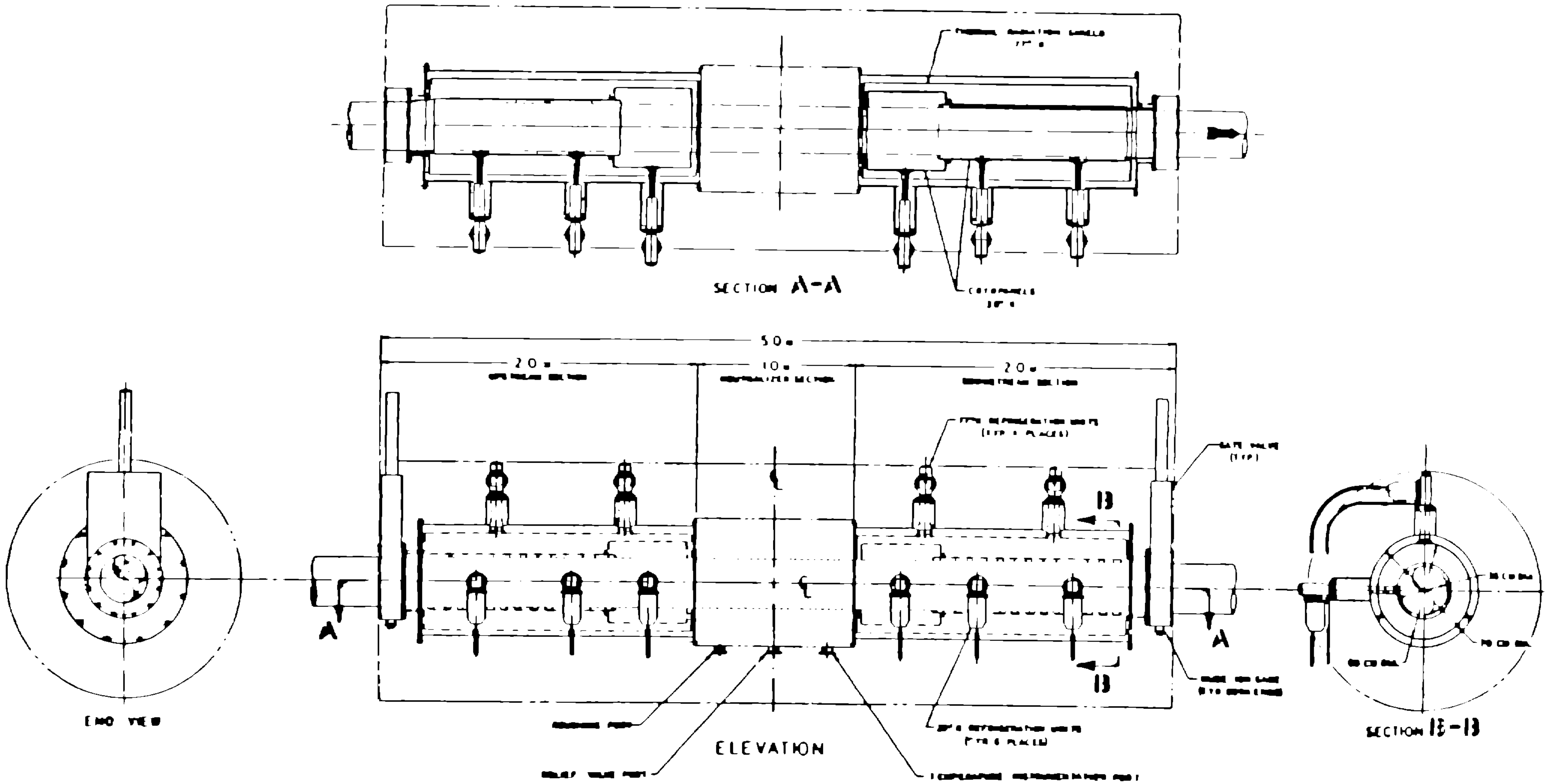
BTA-1
NEUTRALIZER



9. Cryopump System Configuration

Two design study contracts were awarded to provide conceptual designs for the cryopanel system. One contract was awarded to CVI, Inc. in Columbus, OH., the other to Air Products and Chemicals,Inc. in Allentown, PA. As previously discussed, there will be six two-stage heads attached to the 20°K cryopanels and four single-stage heads on the thermal shields. The coneptual design layout shown here is from CVI. It gives a good scaled picture of what the gas neutalizer system will probably look like. One correction that should be noted is that the overall length of the neutralizer is 6 meters, not 5 meters as CVI has shown. The difference is the cryopanel sections will be a full two meters long before transitioning to the valve.

CRYOPUMP SYSTEM CONFIGURATION



10. Foil Neutralizer

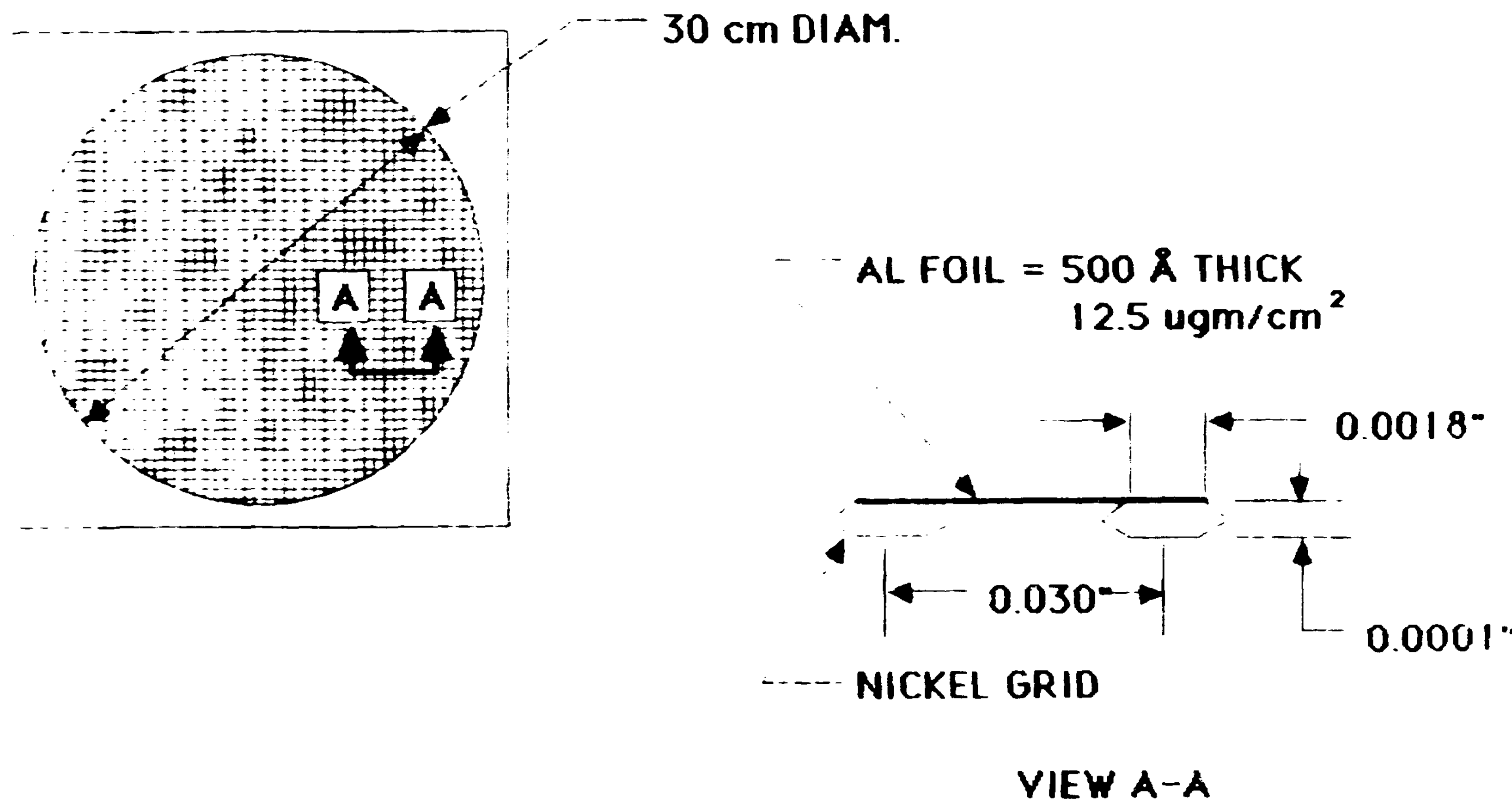
The back-up concept for the gas neutralizer is a foil neutralizer. A foil neutralizer consists of a solid, thin foil of aluminum or carbon on a supporting grid structure made of nickel or some other suitable material.

One of the major concerns with using foils is their fragile nature. The figure shows dimensions for an aluminum foil and nickel grid. For aluminum, the calculated optimum target thickness is 5.0 $\mu gm/cm^2$. When the density of aluminum is considered with this parameter, the thickness of the foil can be calculated and is 500Å. Obviously, a material this thin needs some kind of supporting structure, but that supporting structure can not be very big or substantial because it will absorb a large fraction of the particle beam and heating of the grid will be a problem. Therefore, a very small grid must be used. Typical dimensions of the grids that have been used are shown. Because of their fragile nature, foils and grids of the 30 cm diameter size required for GTA-1 have not been made routinely . It has been a development process, and only in the last couple of months has there been promising progress made with the foils. Foils 5 cm in diameter have been successfully tested on the beamline at Argonne National Lab in conditions that are more severe than is expected in GTA-1. Recently Oak Ridge National Lab, who has been supplying the foils, has stated rather optimistically that they are very confident they can produce 30 cm diameter, single-piece foils of the correct thickness.

Some of the questions that still remain to be investigated and answered about foils are: (1) Will Oak Ridge really be able to produce the larger diameter foils? (2) Will the larger diameter foils hold up as successfully in beamline tests? (3) Due to their fragile nature, will the foils be able to withstand the forces of launch in a space vehicle? (4) If not, does it make sense to use foils for GTA-1 if we know they will not work in ISE-1? (5) Can the foil technology be expanded to be useful in the sizes needed for GTA-2?

FOIL NEUTRALIZER

GTA-1
NEUTRALIZER



III.F. BEAM SENSING

(Beam Scoring, $H^{\cdot}$, H^- & H^+ Beam Stops)

III.F. BEAM SENSING

III. F. BEAM SENSING

1. Introduction.

a. Requirements.

The stated requirements on the output beam direction sensing system are simple. First, it must measure the nominal direction of the beam centroid to a resolution of not worse than 10 micro-radians. Second, it must determine the focus characteristics of the beam to assure an acceptable spot size. Finally, some form of redundancy is needed to assure that beam quality is as required. The term "scoring system" has been used to describe this verification. To completely fulfill the mission of the GTA-1, its beam sensing system must be capable of providing an adequate test of the concepts and components planned for use on the ISE-1 platform. An unstated, but very important, requirement for the GTA-1 sensing system is the verification and qualification of the output optics and beam expansion telescope. No other system is capable of making this measurement; and the beam sensing system cannot correctly perform its function until the delivered beam is of acceptable quality.

b. Approach.

The bulk of the design effort on the GTA-1 beam sensing system will focus on two areas. First, there must be a system suitable for the complete measurement of the beam emerging from the output telescope. This telescope qualification system can serve the dual function of providing beam scoring information. The second major system will develop one of the non-interceptive beam sensing techniques. Some form of the LRF (Laser Resonance Fluorescence) is favored, but both ICA (Intra-Cavity Absorption) and emission Doppler are possibilities.

Many of the components and subsystems on the GTA-1 design will be tested and verified on the ANL(Argonne National Laboratory) 50 MeV H^- beamline prior to incorporation into GTA. The ability to perform design verification on a separate, immediately available test bed of the proper energy will be an indispensable tool in the final selection of GTA sensing equipment.

REQUIREMENTS ON GTA-1 BEAM SENSING SYSTEM

- MEASURE H^0 BEAM CENTROID DIRECTION TO 10 μrad IN POLAR ANGLE
- DEVELOP A SCORING SYSTEM TO DEMONSTRATE THAT PRECISION
- PROVIDE DESIGN SUPPORT FOR ISE-1

DESIRABLES:

- INCORPORATE A SYSTEM THAT IS ISE COMPATIBLE
- MEASURE CENTROID DIRECTION IN LESS THAN ONE MACROPULSE
- DETERMINE BEAM FOCUS INFORMATION
- INTERCEPT VERY SMALL FRACTION OF BEAM CURRENT
- SENSE AND TRACK A MOVING BEAM
- REDUCE DESIGN RISK FOR GTA-2 SYSTEM

CHM-VG-11.262

c. System Design.

It is almost certainly true that any one of several techniques could meet the minimum GTA-1 beam sensing requirements; however, the interest is in selecting the one that best meets the unique combination of requirements for all program elements.

For higher beam powers and higher duty factors, some form of non-interceptive technique is mandated. Of the interceptive techniques, the wire shadow is most attractive because it intercepts minimum beam. Unfortunately, there is question about the ultimate pointing precision achievable by a mechanical wire shadow. Pinholes, a viable technique for the short-term requirements of telescope evaluation on low-power, low-duty-factor beams, must soon be abandoned because of intercepting a large beam fraction. Pinhole techniques might remain viable for working in the beam periphery.

All identified non-interceptive techniques are large, complex, and suffer from some uncertainty in reference alignment with the platform pointing axis. LRF techniques have the additional problem of fighting detection backgrounds and usually incorporate lasers unproven in space.

For the commissioning stage on GTA-1, pinholes can be used with a fluorescent screen coupled to high-resolution video cameras. This technique is relatively simple and allows a direct, unambiguous qualificaiton of the output beam. Meanwhile the GTA team will pursue development of issues pertaining to several of the non-interceptive candidate techniques. To provide direct support for the ISE-1 program, development will continue on a minimally interceptive direct sensing scheme.

DIRECTION SENSING TECHNIQUES

INTERCEPTIVE	ADVANTAGES	ISSUES
PINHOLE	SIMPLE, DIRECT	SURVIVAL, RADIATION BEAM LOSS
WIRE SHADOW	MINIMALLY INTERCEPTIVE	ULTIMATE RESOLUTION, DETECTION METHOD
NON-INTERCEPTIVE		
(LRF, ICA, DOPPLER)	NO FUNDAMENTAL BEAM POWER LIMIT	BACKGROUNDS, COMPLEXITY, RESPONSE TIME, SPATIAL RESOLUTION

CHM-VG-11,278

d. Laser Resonance Fluorescence Concept.

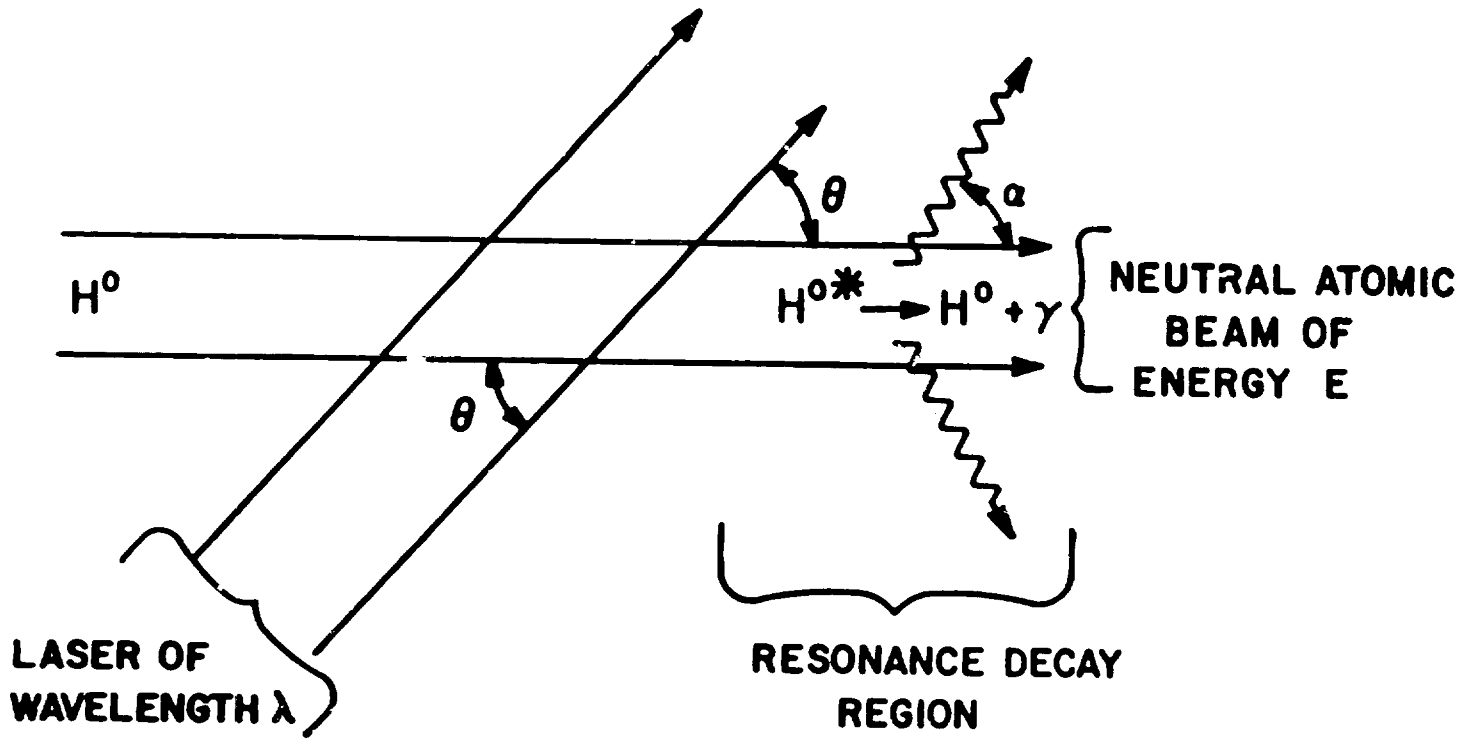
The basic concept common to all LRF schemes is depicted on the facing page. A laser beam of suitable wavelength and low divergence intercepts the NPB at an angle Ø, often referred to as the "*magic*" *angle*. *The magic angle is that laboratory angle at which the laser beam appears to intercept the* NPB at right angles to the moving frame of reference. Only at this magic angle does the momentum spread of the NPB have minimum impact on the absorption line width. This "magic" angle is a function of the energy of the NPB, given by $Ø = \cos^{-1}(\beta)$, where $\beta = v/c$. The effective laser frequency as seen by the moving neutral particle is given by $\nu' = \nu$ gamma $(1-\beta \cos ø)$, where ν is the laser frequency in the laboratory. For the LRF to operate correctly, ν' must be equal to the frequency of the sharp resonance line to be excited. If the magic angle ø and the laboratory laser frequency ν are chosen as above, there will be a sharp resonance for excitation of the neutral particles. Degree of absorption will be a function of the ß of the beam and the precise angle Ø between laser and particle beams.

The actual parameter sensed is the emission from the excited state of the neutral atom as it decays to a lower energy state. There will be a detectable peak in this emission when there is the best match for the excitation laser. High-efficiency detectors may be used in the resonance decay region to detect the point at which there is an optimum match between either the magic angle or the laser frequency. Either the angle or frequency may be scanned in time to permit mapping out the resonance. For a complete, two-dimensional sensing system, this arrangement must be duplicated in the orthogonal dimension as well.

The basic concept for LRF beam sensing has been proven in experiments at the Los Alamos Van de Graaff. Planned *experiments at the Argonne National Laborarory Neutral* Beam Facility, the HIRAB *beam on the* Meson Physics Facility at LANL, and the GTA-1 beam will verify the LRF performance at beam energies of greater interest.

The LRF concept offers the advantage of a technique that is totally non-intrusive (non-interceptive) to the NPB and that shows promise of meeting all anticipated precision requirements. Issues to be addressed are the system complexity, laser reliability, and signal to background ratios.

LRF BEAM SENSING CONCEPT



e. ISE-1 Compatibility.

The GTA-1 beam sensing program will offer unique and valuable support to the ISE-1 program. In the early stage, telescope qualification tests at both ANL and GTA-1 will completely characterize the performance and quality of the large-diameter particle beam emerging from the output telescope. Even with a non-prototypic beam, this test will verify the optics design codes. Also in this initial phase, accelerator performance and characteristics will be measured.

There will be some form of mechanical sensing or scoring system on GTA-1. Operation of this system will serve an an important test of at least one mechanical system that might be considered for use on ISE-1. A minimum of one non-interceptive sensing technique will be incorporated on GTA-1. This will offer the first opportunity to test an integrated non-interceptive system.

One specific test to be performed is the evaluation of small-diameter fluorescent fibers inserted into the beam. This test is a logical and important extension of the fluorescent screen that will be used for initial telescope evaluation. If successful, it will offer the opportunity of a minimally interceptive direct sensing scheme that can qualify output optics performance, perform primary beam sensing, or serve as an on-line scoring system for a different technique. This particular concept offers the design simplicity of a direct, interceptive system with a simple detection scheme.

The entire output system will be configured such that any of several major components may be separately replaced by units supplied by contractors to facilitate the qualification of other sensing systems.

GTA-1 BEAM SENSING SYSTEM PROVIDES VALUABLE ISE-1 SUPPORT

- OUTPUT OPTICS DESIGN CODE VERIFICATION
- TESTS OF SELECTED COMPONENTS AND CONCEPTS
- SYSTEM LEVEL VERIFICATION ON GTA-1

CHM-VG-11,393

2. Component Descriptions.

a. Options

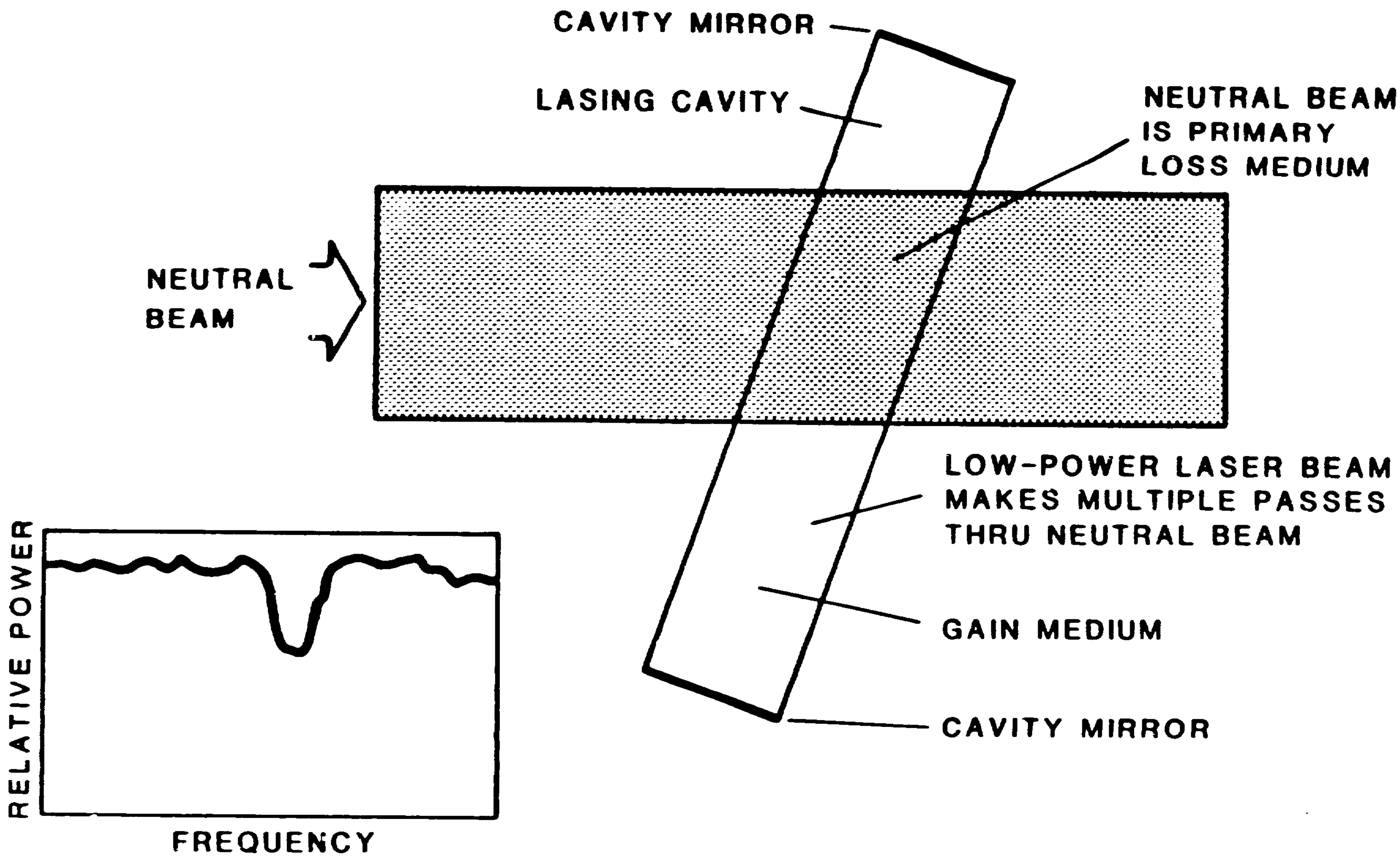
1. Intra-cavity Absorption.

The de facto standard for non-interceptive techniques is that of LRF. Unfortunately, this concept suffers from a few potentially serious disadvantages. These include susceptibility to backgrounds, including photon fluorescence, ionizing radiation, free ions, and electrons near the detectors. The LRF system tends to be large, heavy, fragile, and complex. In at least some cases, high-power exotic lasers may be required. A probable technique for determining beam direction with the conventional LRF is to scan the laser beam in time over a small angular range and compare the number of detected photons as the resonance peak is mapped. This procedure makes the technique susceptible to beam-current fluctuations. Most of these potential problems could be automatically eliminated or minimized by use of an alternative technique called intra-cavity absorption (ICA).

The ICA concept is depicted on the facing page. A low-power (few mW) cw laser is used. The NPB passes through the laser cavity, intersecting the laser beam near the magic angle, and serves as the primary loss mechanism. A large number of adjacent wavelengths are excited in the cavity. The Doppler-shifted wavelength nearest the resonance will be maximally attenuated. The location of a dip in the spectral display of laser power vs frequency will be indicative of the attenuated wavelength, and hence a direct indication of output beam angle.

By employing this display technique, one may achieve simultaneous detection of beam direction over a finite wavelength interval. Also because this technique does not rely on observing fluorescence from the NPB, it is completely immune from photon backgrounds. Only a very low power laser is needed. Unfortunately, it is still necessary to have a laser at exactly the correct wavelength to match the beam energy and magic angle. To function properly, this laser must have the proper bandwidth and possess adequate stability.

The major issue on this technique is to develop the correct combination of sensitivity and response time with a workable system. The magnitude of the dip in the frequency spectrum is limited by the beam current density, beam divergence, and coherence time of the laser system. An experimental program to address these issues is essential to assess ultimate feasibility of this potentially promising sensing method.



CAVITY MIRROR
LASING CAVITY
NEUTRAL BEAM IS PRIMARY LOSS MEDIUM
NEUTRAL BEAM
LOW-POWER LASER BEAM MAKES MULTIPLE PASSES THRU NEUTRAL BEAM
GAIN MEDIUM
CAVITY MIRROR
RELATIVE POWER
FREQUENCY

CHM-VG-10,932

2. Ground state excitation for LRF.

One of the principal advantages of using direct ground state excitation is that at least 75% of neutral atoms emerging from the neutralizer cell are in the ground state. This means that one can get the highest potential signal from this process. Also, atoms in the various excited states are scattered through a larger angle than ground state atoms. Making a centroid direction determination from higher excited states means measuring a broader direction spread.

If a transverse electric or magnetic field is used to quench (by mixing) some of the excited states, the effective background signal may be significantly reduced. Ground state excitation thus has both the largest potential signal and a smaller possible background. The signal to background ratio is the most important single parameter for any LRF sensing concept.

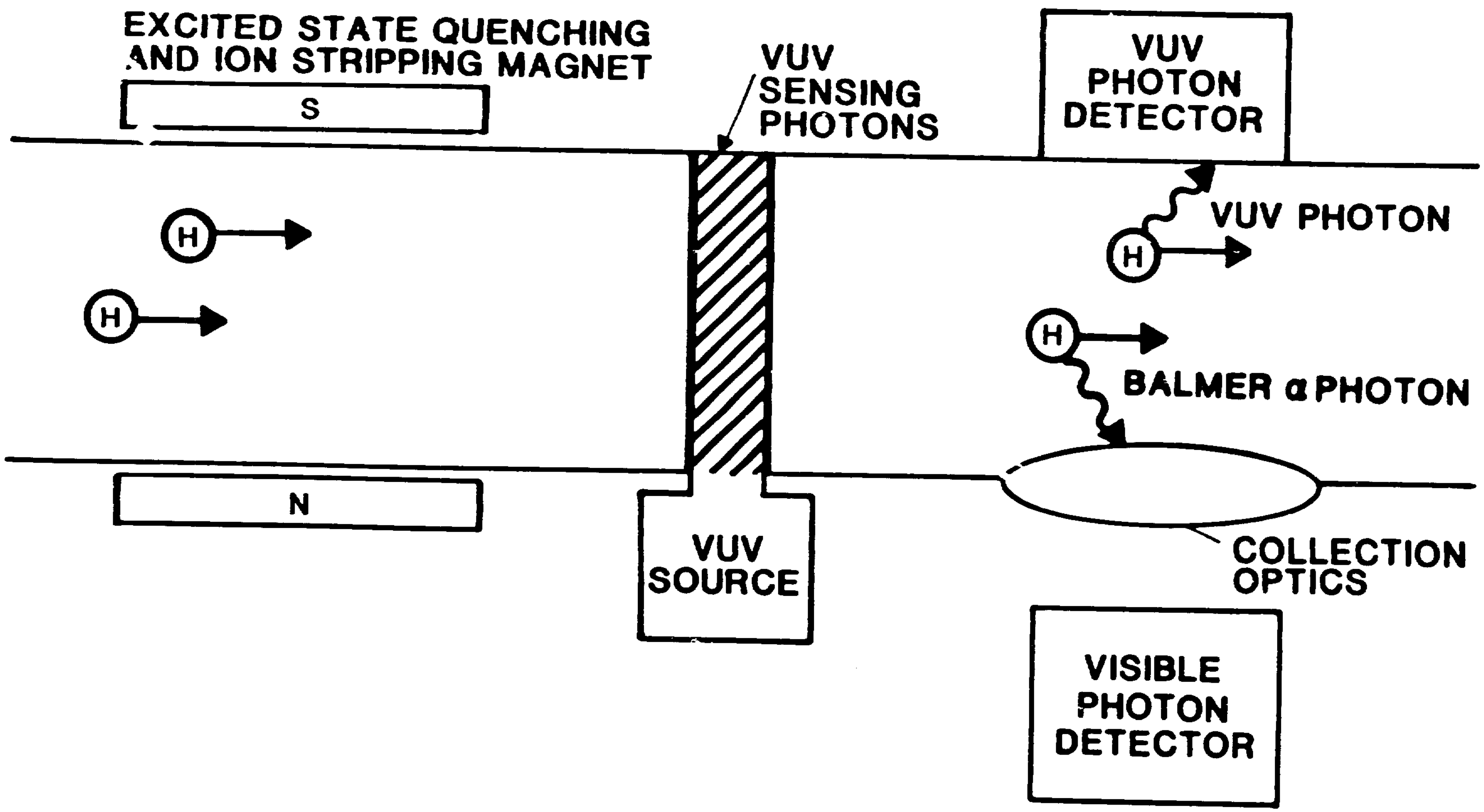
The unshifted Lyman-beta line is at 102.6 nm. For a 50 MeV beam excited at the magic angle, a wavelength of 97.4 nm is needed. This wavelength, significantly shorter than the Balmer series, means that an acceptably divergent laser beam is about one-sixth the diameter of an equivalent Balmer-wavelength laser beam. It is also a small fraction of the neutral particle beam diameter. For this condition, it becomes feasible to think of spatially probing the NPB to measure beam focus directly.

Detection wavelength can be at either the Lyman-beta or the visible Balmer-alpha (at 656 nm, unshifted). Detection in the visible offers dramatic simplification over working in the VUV.

The most significant issue facing the use of ground state excitation is the generation of the exciting laser wavelength. Lasers operating directly at 97 nm are not yet feasible. The frequency mixing scheme depicted on the facing page is an acceptable technique, but has an overall efficiency of less than 1E-6. Nevertheless, working with presently available laser amplifiers, it should be possible to saturate the Lyman-beta transition. Each of the generation techniques has been proven independently. It remains to show the feasibility of constructing a operable system incorporating all generation steps.

Another attractive feature of this concept is the simple scaling to all beam energies of interest. Simply changing the dye used in the "local oscillator" will allow covering all energies from 50 to 200 MeV. Further, at a beam energy of about 223 MeV, the relatively unreliable dye laser can be eliminated completely.

GROUND STATE BEAM SENSING CONCEPTUAL BLOCK DIAGRAM



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3. Experiments.

A comprehensive set of small experiments on numerous concepts and components is an important part of the GTA-1 beam sensing program. This program will include non-beam (offline) tests, experiments at two different beamlines at ANL, and experiments on GTA-1 itself. The off-line experiments will include items such as retesting a simple ICA cavity to develop faster tuning, better detection techniques, and measurement of time periods. A suitable VUV laser for ground state excitation will be developed off-line as well.

. Tests on the unexpanded ANL Phase-A beamline will include the determination of shield effectiveness against both prompt gammas and neutrons. Additional spectral measurements will be made in both the Balmer and Lyman series. An early test will characterize the shadow of a small-diameter wire inserted in the beam. Optical scintillators (both thin sheets and fibers) will be evaluated in characteristic beam densities and energies. The performance of different prototypic detectors will be monitored as a function of gas pressure and species. The angular divergence introduced by solid foils is an unresolved issue. An early test will be tailored to perform this high-precision measurement.

An expanded. large-diameter. nearly parallel beam will be available from the ANL Phase-B beamline. Beam expansion is the result of an output telescope whose performance must be measured by the beam sensing system before true beam sensing runs are begun. Later, beam sensing experiments will be made with both direct, interceptive techniques and non-interceptive methods. In this process. the GTA-1 beam sensing system will be largely qualified. Later, it should be feasible to perform some simple beam-steering and direction-control experiments.

Reliable beam is available at an early date from the ANL beamline, but experiments capitalizing on the increased beam current, longer pulse length, and higher duty factor will be performed on GTA-1. One of the important early runs is qualification of the output telescope with significant space charge. The testing of LRF (or other non-interceptive techniques) will be performed at higher beam currents and duty factors. With prototypic parameters, this test can provide complete design verificaion for ISE-1. Because of improved integration with the ion accelerator, it should be possible to perform more comprehensive beam-steering and focus-control experimental runs than were possible at ANL.

EXPERIMENTAL EMPHASIS

- THE FOCUS AT ANL WILL BE ON PERFORMING MAXIMUM NUMBER OF BASIC EXPERIMENTS. RELIABLE BEAM IS AVAILABLE NOW

- BEAM SENSING EXPERIMENTS AT GTA-1 WILL FOCUS ON:
  - THOSE ISSUES THAT ARE UNIQUE TO GTA-1
    - SPACE-CHARGE EFFECTS
    - INCREASED BEAM INTENSITY
    - LONGER PULSE LENGTH

- BEAM CONTROL SYSTEM ASPECTS FOR GTA-2
  - INCORPORATION OF FEEDBACK SYSTEMS TO CONTROL BEAM POSITION AND STEERING

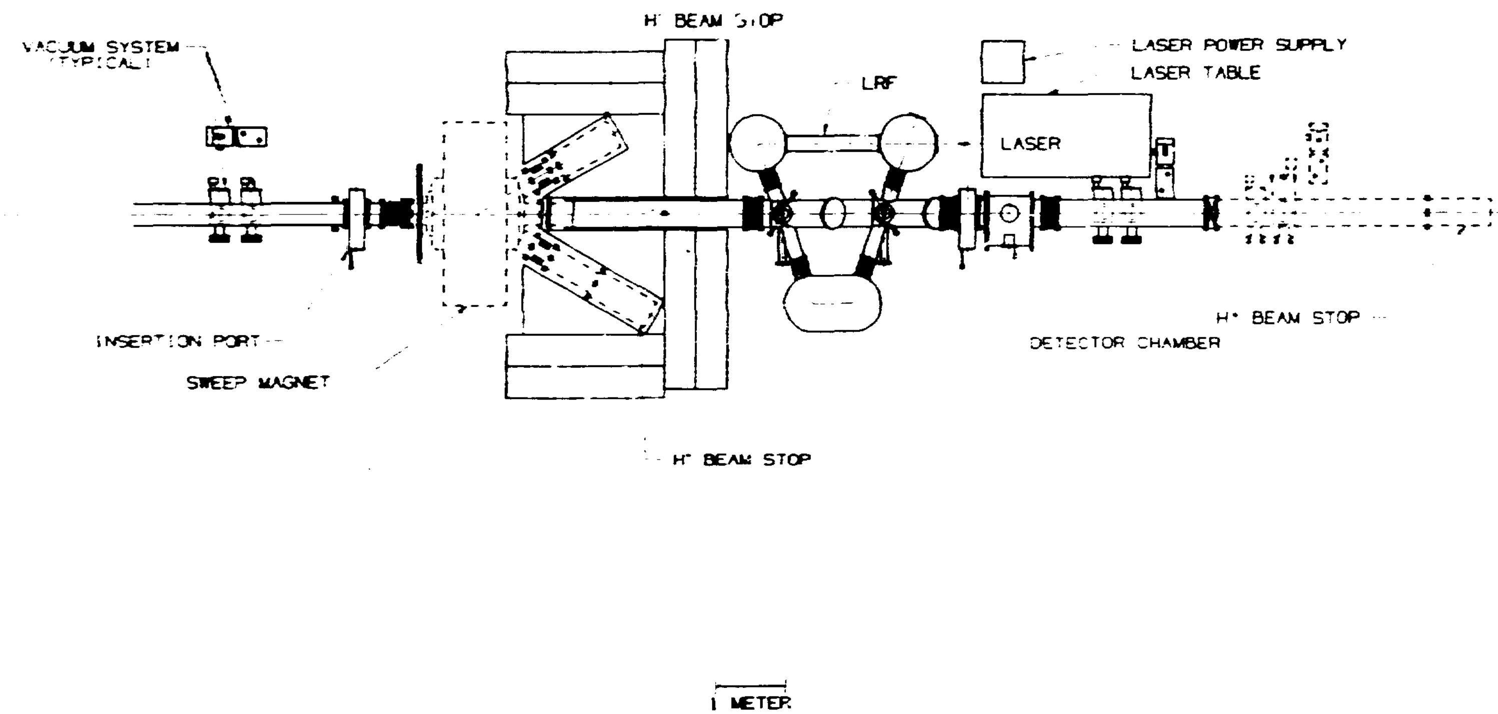
4. Selection.

There were several reasons for the selecion of the two independent beam sensing systems on GTA-1. First, it was considered absolutely essential to provide a system that would completely measure and characterize the performance of the beam delivered to the beam sensing area. Without a high-quality, nominally parallel beam, high-precision beam sensing is not possible. The selected, interceptive pinhole concept seems entirely appropriate for the output telescope qualification. This system can be used on both the H^- beam upstream of the neutralizer, and on the neutralized beam downstream. The telescope qualifciation system will determine the spatial location of centroids of many (perhaps hundreds) of beamlets across the beam profile, and will determine high-resolution profiles of a selected few of the beamlets. In this way, both the beam aberrations and the transverse emittance of individual beamlets may be measured.

The selected non-interceptive technique should support follow-on programs such as GTA-2. The selected technique should be compatible with GTA-2 precision requirements and should offer an opportunity for incorporating space-qualified components. Based on the large number of successful experiments performed at Los Alamos and elsewhere, some version of the LRF concept seems to offer the highest probability of technical success. The associated development program will continue with investigations into direct sensing schemes that intercept a smaller fraction of beam current, and with non-interceptive alternatives to LRF.

The GTA-1 sensing program was designed to be complementary, not competitive, with the ISE-1 program. It will offer the only early opportunity to evaluate several of the possible sensing schemes on a NPB system that is functionally similar to the ISE-1 configuration.

NPB
BEAM SENSING



P-12
MECHANICAL ENGINEERING

5. Status.

There are several concurrent activities on the GTA-1 beam sensing program. A detailed design is proceeding on a pinhole-based output telescope evaluator. Meanwhile, major identified issues are being addressed on various non-interceptive sensing concepts. The "conventional" LRF technique with laser excitation from the 2S excited state is being pursued. Activities in support of this technique include measurement of various backgrounds, determination of detector performance, and preliminary equipment and system designs.

A moderate effort is proceeding on investigation of ground state excitation because of the advantages listed earlier. If the ground state excitation laser can be developed, this technique would be favored for LRF. In parallel with LRF techniques, a limited investigation is continuing on the ICA. Initial work consists of restoration of an ICA experiment performed years ago in the MFE-CTR program. A planned follow-on, more sophisticatd experiment should soon answer questions about ultimate ICA system feasibility for use on NPB's.

A large fraction of the near-term activities on GTA-1 beam sensing will focus on fundamental experiments to be performed on the 50 MeV H^- and neutral beam line at Argonne National Laboratory. Beam parameters at ANL include beam currents of 1-10 mA, nominal pulse lengths of 100 micro-seconds and a beam repetition rate of 3 pps. While not a perfect match for the GTA-1 parameters, the ANL beam offers a convenient, early and reliable test bed for evaluating most GTA-1 sensing concepts and components. The extremely high reliability of the ANL beam is largely due to the fact that it has been operational since about 1961. The design risk for the GTA-1 and ISE-1 systems can be dramatically reduced by a timely and comprehensive experimental program at Argonne, where beam parameters are acceptably close to those of GTA-1.

PROJECTED NEAR-TERM BEAM SENSING STRATEGY

- PROVIDE EQUIPMENT AND EXPERIMENT DESIGNS FOR GTA-1

- PERFORM MAXIMUM NUMBER OF PROOF-OF-PRINCIPLE EXPERIMENTS AT ANL

RATIONALE:

- THE ANL LINAC IS OPERATIONAL, RELIABLE AND AVAILABLE

- NEAR-TERM, SMALL-SCALE EXPERIMENTS AT ANL WILL PROVIDE TIMELY DESIGN INFORMATION FOR GTA-1 AND ISE-1

CHM-VG-11,273

6. Key Milestone Dates.

The calculations and off-line experiments that are designed to determine the ultimate feasibility of ground state excitation should reach a point by the end of fiscal year 1986 that an intelligent assessment can be made of the need for further work. This issue hinges almost entirely on the feasibility of assembling a viable VUV laser system.

Conceptual design has been completed, but many details remain to be completed, on an optimum technique for measuring the output telescope performance. This system must measure actual output beam and calibrate the appropriate design codes.

Actual characterization of the ANL expanded Phase-B beamline is likely to require several months of intermittent beam time. Initial qualification runs will commence soon after installation of the output telescope in early spring, 1987.

Completion of final design for the GTA-1 beam sensing system must await the completion of a number of important off-line and ANL beam experiments. Beam runs with prototypic gear on the ANL expanded Phase-B beamline will be an important final verifcation of GTA-1 designs.

The present schedule calls for completion of all equipment fabrication for the GTA-1 beam sensing system by May of 1988. Much of this equipment will be returned from ANL, or will be a duplication of that used at ANL. This milestone date is compatible with the installation of all other GTA-1 systems.

MAJOR GTA-1 BEAM SENSING MILESTONES

• DETERMINE FEASIBILITY OF GROUND-STATE EXCITATION	10/86
• COMPLETE DESIGN OF ANL TELESCOPE CHARACTERIZER	12/86
• CHARACTERIZE ANL PHASE-B EXPANDED BEAM	9/87
• COMPLETE DESIGN OF GTA-1 SYSTEM	12/87
• COMPLETE FABRICATION OF GTA-1 EQUIPMENT	5/88

CHM-VG-11,392

III.G. RADIO-FREQUENCY (RF) POWER

III.G. RF SYSTEM

GTA-1 RF SYSTEM REQUIREMENTS

FREQUENCY	425 MHz
BANDWIDTH (1 dB POINTS)	±2.5 MHz
PULSE LENGTH	30 TO 350 μs
OPERATING DUTY FACTOR *	0.1%
AMPLITUDE CONTROL	±0.5%
PHASE CONTROL	±0.5°
TUBE TYPE **	KLYSTRON
TUBE OUTPUT CONNECTOR	WR-2100 WAVEGUIDE
ACCELERATING STRUCTURE INPUT	COAXIAL LINE, LOOP DRIVE

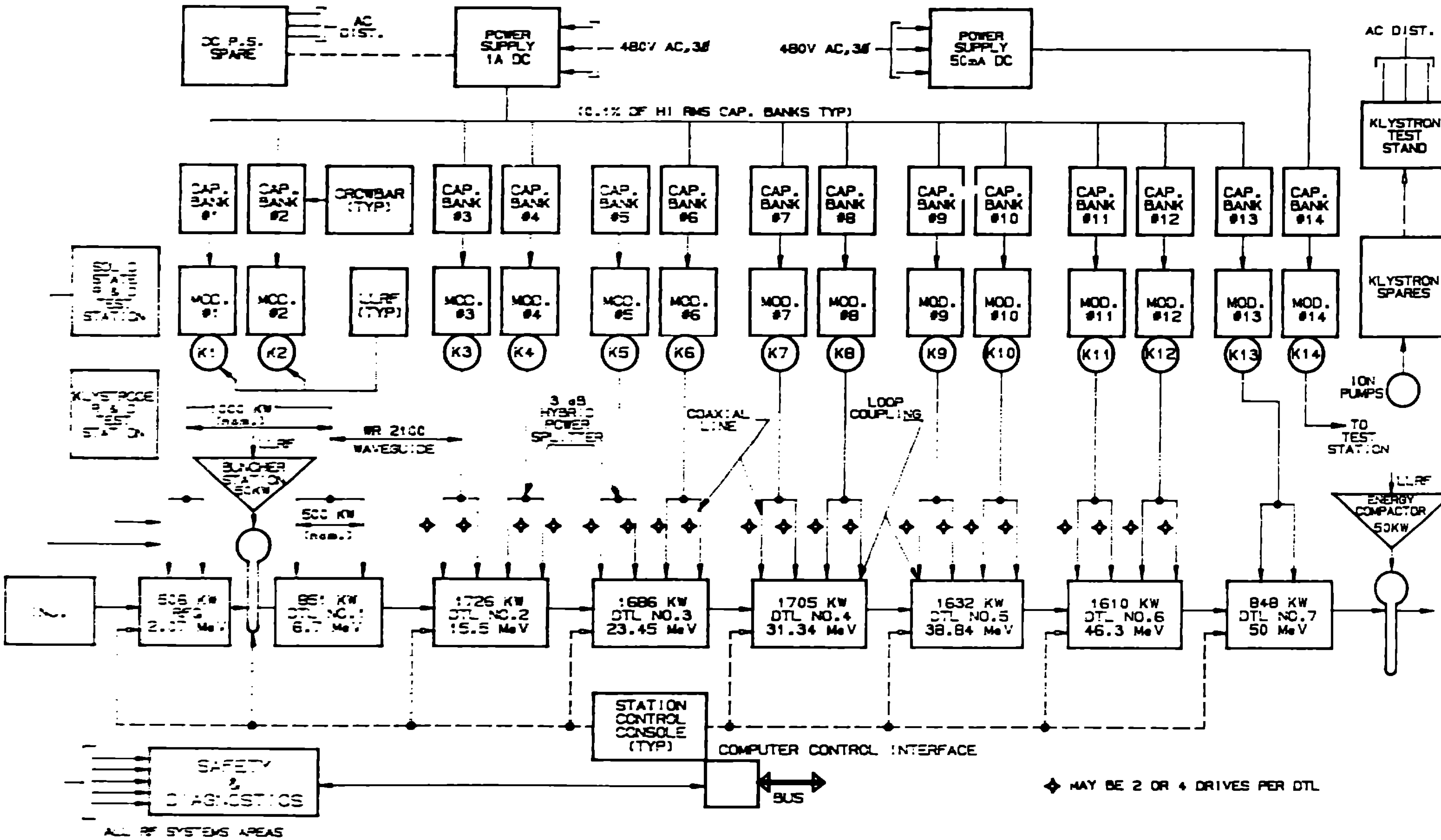
* PROVISION WILL BE TO RECONFIGURE RF SYSTEM TO TEST ONE DTL TANK AT 5% D.F.

** PROVISION WILL BE MADE TO TEST 500 kW SOLID STATE RF UNITS

RFQ	0.506 MW
BUNCHER	0.050 MW
DTL 1 (RG DTL)	0.851 MW
DTL 2	1.726 MW
DTL 3	1.686 MW
DTL 4	1.705 MW
DTL 5	1.632 MW
DTL 6	1.610 MW
DTL 7 (VERNIER)	0.848 MW
MOMENTUM COMPACTOR	0.125+ MW
	10.739 MW (NO MARGIN)

RF SYSTEM

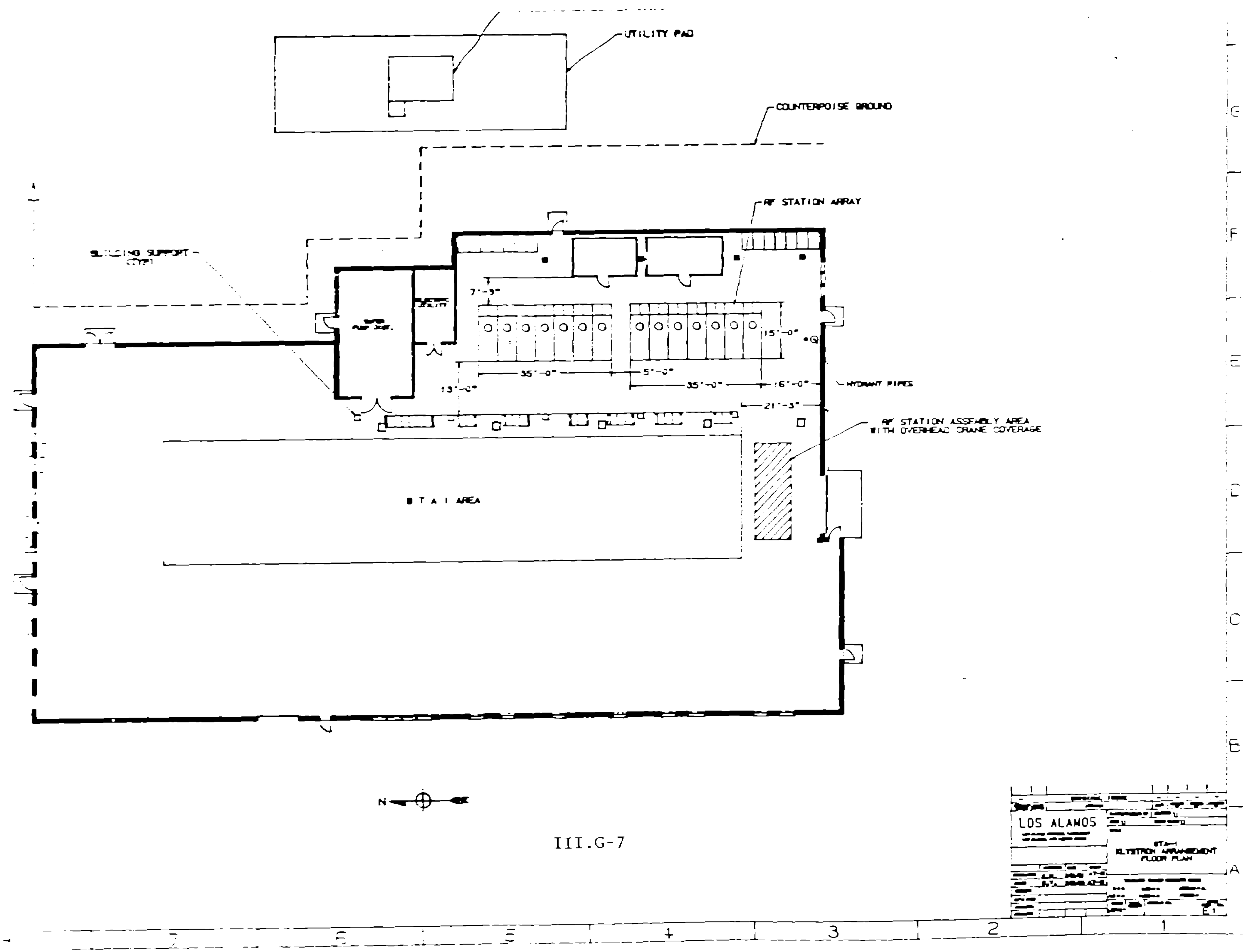
- o MAIN POWER SUPPLY FEEDS THIRTEEN ACCELERATOR STATIONS
- o SPARE POWER SUPPLY INSTALLED ON UTILITY PAD
- o SEPARATE POWER SUPPLY FOR AUXILIARY STATION (#14)
- o 50 kW BUNCHER STATION AND MOMENTUM COMPACTOR UTILIZE GRIDDED TUBES
- o SOLID STATE AND KLYSTRODE MODULES CAN BE ACCOMMODATED FOR TEST
- o INDIVIDUAL CAPACITOR BANKS ISOLATED FROM EACH OTHER
- o NUMBER OF DRIVE PORTS FOR DTL's 3 THROUGH 6 TBD



GTA-1 FUNCTIONAL RF DIAGRAM

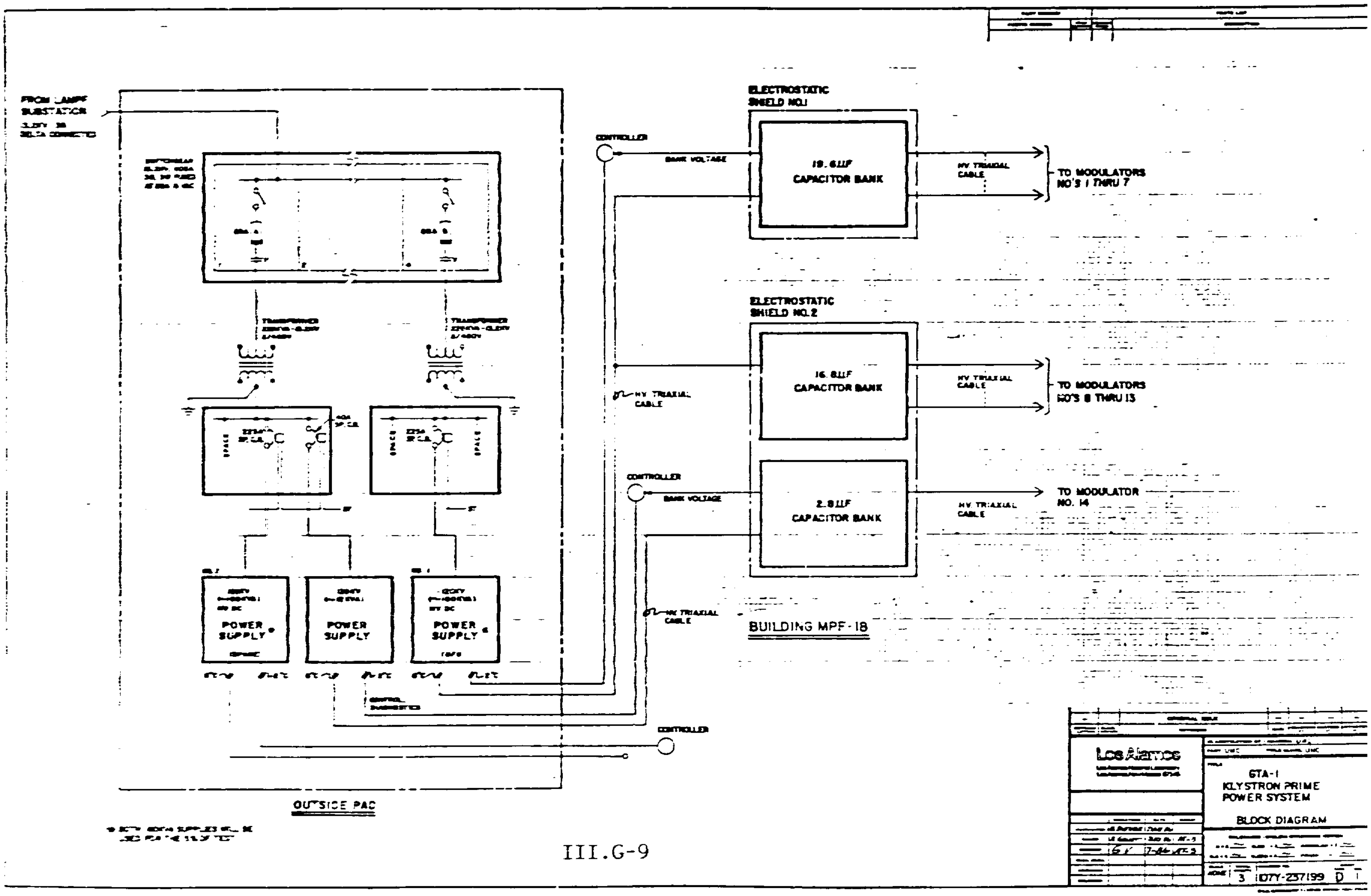
RF STATION ARRANGEMENT

- MODULAR RF STATION ARRANGEMENT
- LIMITED HEAD ROOM
- RF STATION STAGING AREA WITH CRANE COVERAGE REQUIRED
- CAPACITOR BANKS IN SHIELDED ENCLOSURES ALONG EAST WALL
- UTILITY PAD FOR POWER SUPPLIES OUTSIDE OF MPF-18
- BUNCHER RF STATION NEAR UTILITY ROOMS


UTILITY PAD
COUNTERPOISE GROUND
RF STATION ARRAY
BUILDING SUPPORT (TYP)
7'-9"
15'-0"
35'-0"
5'-0"
35'-0"
16'-0"
13'-0"
HYDRANT PIPES
21'-3"
RF STATION ASSEMBLY AREA WITH OVERHEAD CRANE COVERAGE
N
LOS ALAMOS
KLYSTRON ARRANGEMENT FLOOR PLAN

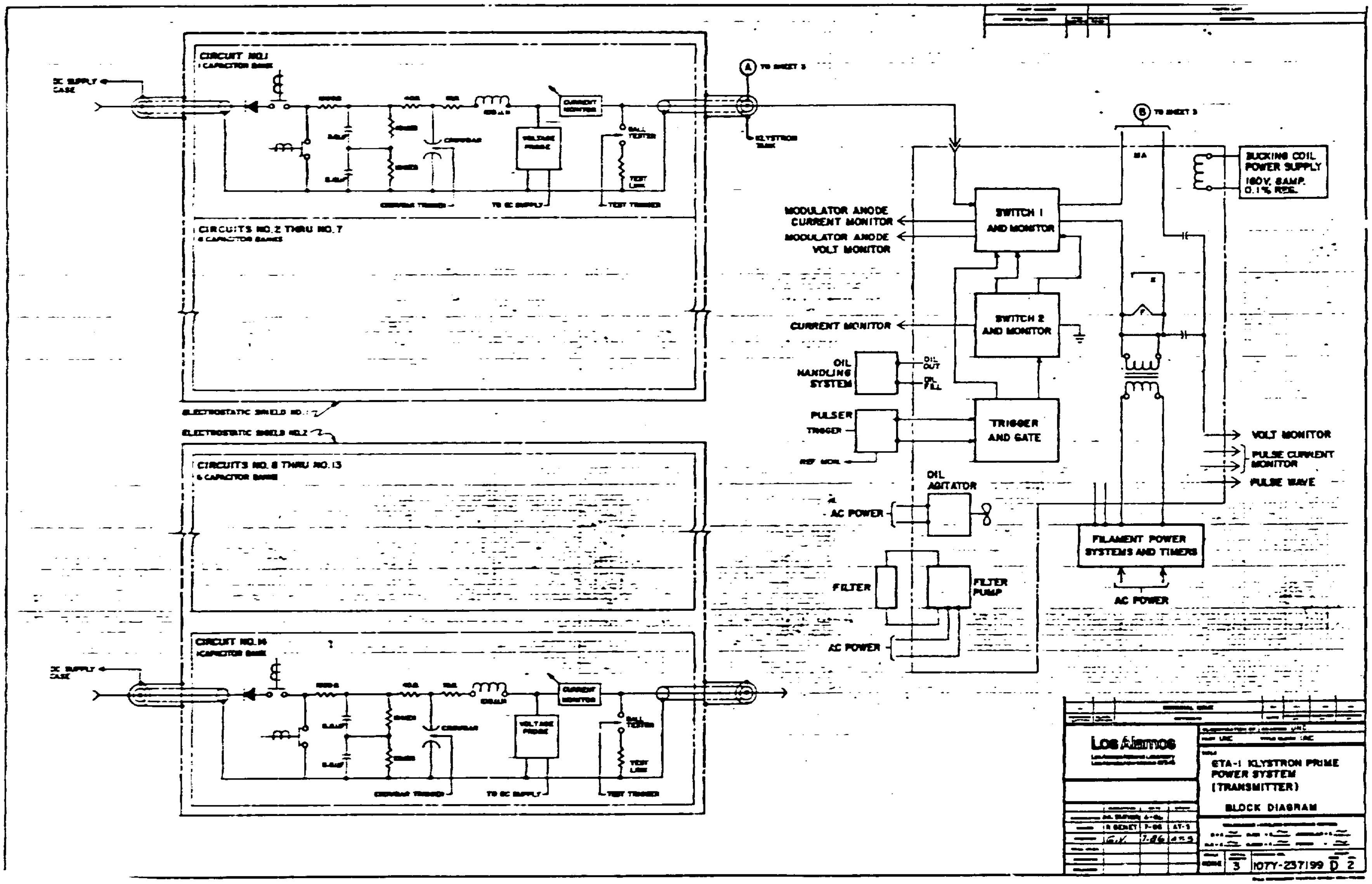
RF SYSTEM PRIME POWER

- 13.2 KV UTILITIES EXIST
- TRANSFORM TO 480 V, 3Ø FOR DC SUPPLIES
- MAIN POWER SUPPLY DRIVES THE 13 ACTIVE STATIONS
- STATION #14 FOR OFF-LINE CONDITIONING
- TRIAXIAL HV DISTRIBUTION CABLE
- 2.8 μF ENERGY STORAGE PER STATION
- ENERGY STORAGE MAY BE CONFIGURED FOR OPERATING ONE STATION UP TO 2 ms AND 5% DUTY


FROM LAMPF SUBSTATION
SWITCHGEAR
TRANSFORMER
TRANSFORMER
POWER SUPPLY
POWER SUPPLY
POWER SUPPLY
CONTROL DIAGNOSTICS
OUTSIDE PAD
CONTROLLER
BANK VOLTAGE
ELECTROSTATIC SHIELD NO.1
19.6 µF CAPACITOR BANK
HV TRIAXIAL CABLE
TO MODULATORS NO'S 1 THRU 7
ELECTROSTATIC SHIELD NO.2
16.8 µF CAPACITOR BANK
HV TRIAXIAL CABLE
TO MODULATORS NO'S 8 THRU 13
HV TRIAXIAL CABLE
CONTROLLER
BANK VOLTAGE
2.8 µF CAPACITOR BANK
HV TRIAXIAL CABLE
TO MODULATOR NO. 14
HV TRIAXIAL CABLE
BUILDING MPF-18
CONTROLLER
Los Alamos
GTA-1
KLYSTRON PRIME
POWER SYSTEM
BLOCK DIAGRAM
3
107Y-237199
D

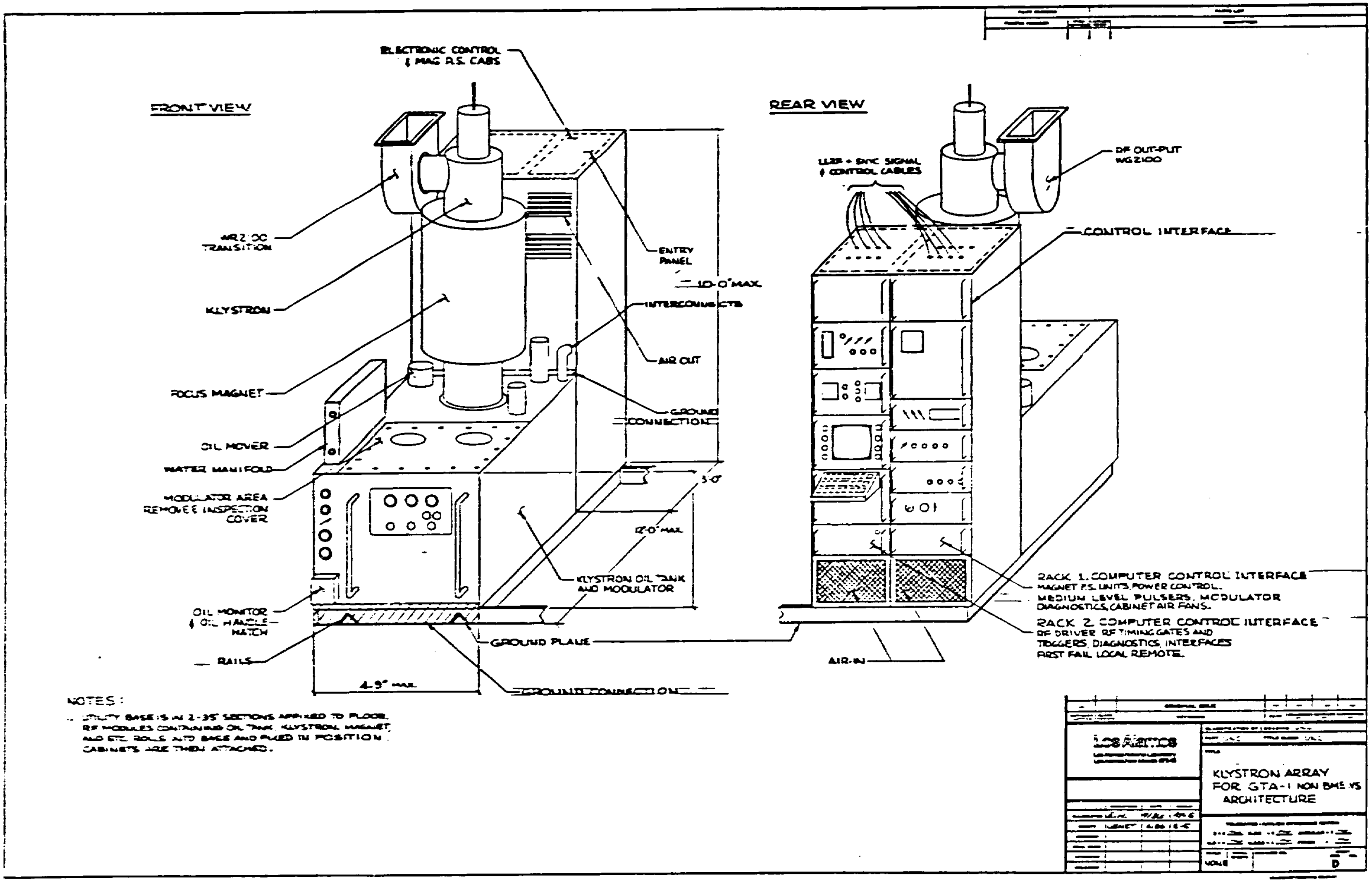
KLYSTRON MODULATOR

- INDIVIDUAL CAPACITOR BANKS
- 2.8 μF PER STATION
- CROWBAR RESPONSE 1 μs
- DI/DT <1000 A/μs
- 10 OHM LIMITING RESISTOR

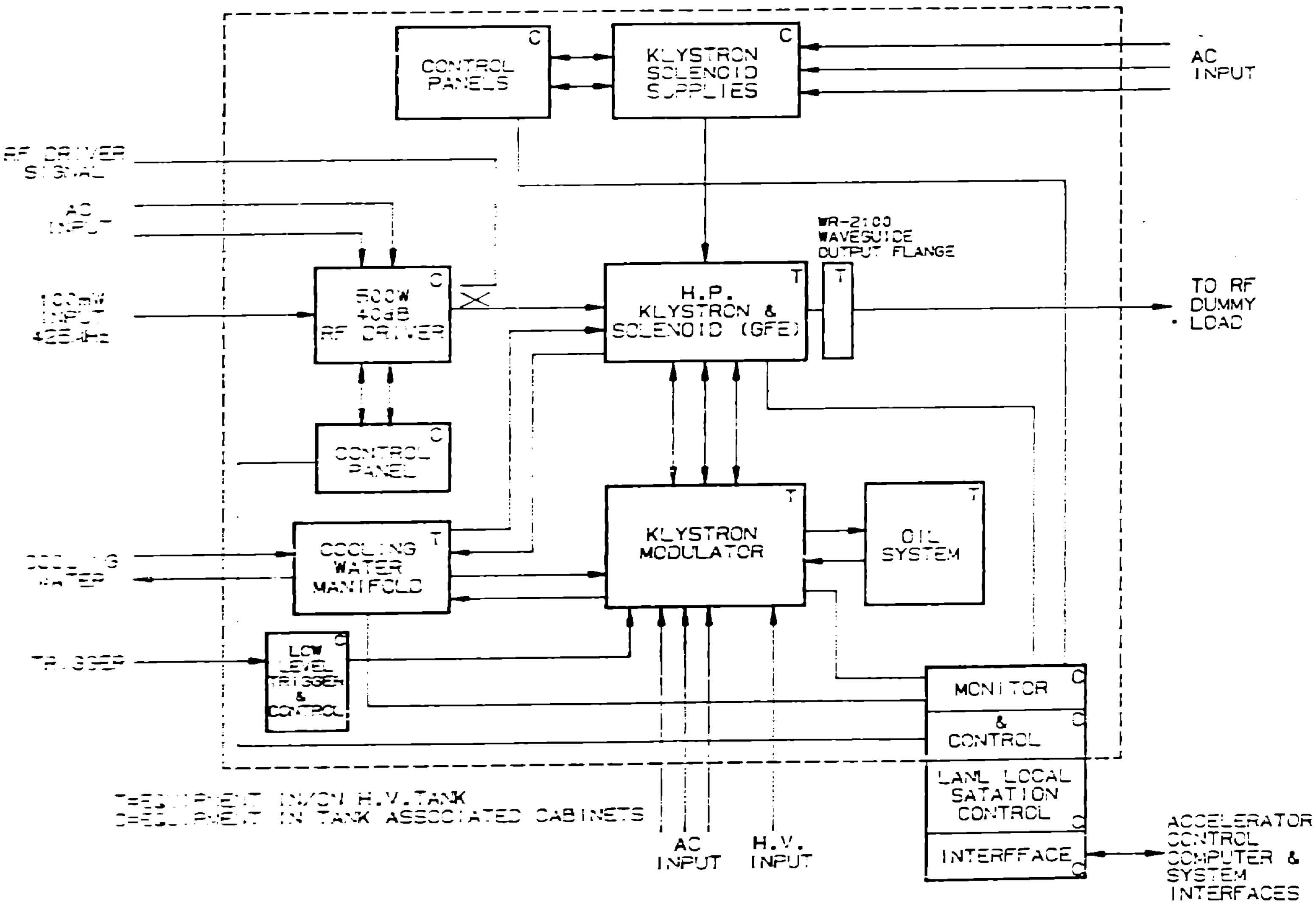

CIRCUIT NO.1
CIRCUITS NO.2 THRU NO.7
ELECTROSTATIC SHIELD NO.1
ELECTROSTATIC SHIELD NO.2
CIRCUITS NO.8 THRU NO.13
CIRCUIT NO.14
A TO SHEET 3
B TO SHEET 3
BUCKING COIL POWER SUPPLY 160V, 8AMP. 0.1% REG.
MODULATOR ANODE CURRENT MONITOR
MODULATOR ANODE VOLT MONITOR
SWITCH 1 AND MONITOR
SWITCH 2 AND MONITOR
CURRENT MONITOR
OIL HANDLING SYSTEM
OIL OUT
OIL FILL
PULSER
TRIGGER AND GATE
OIL AGITATOR
AC POWER
FILTER
FILTER PUMP
FILAMENT POWER SYSTEMS AND TIMERS
VOLT MONITOR
PULSE CURRENT MONITOR
PULSE WAVE
Los Alamos
GTA-1 KLYSTRON PRIME POWER SYSTEM (TRANSMITTER)
BLOCK DIAGRAM
107Y-237199 D 2

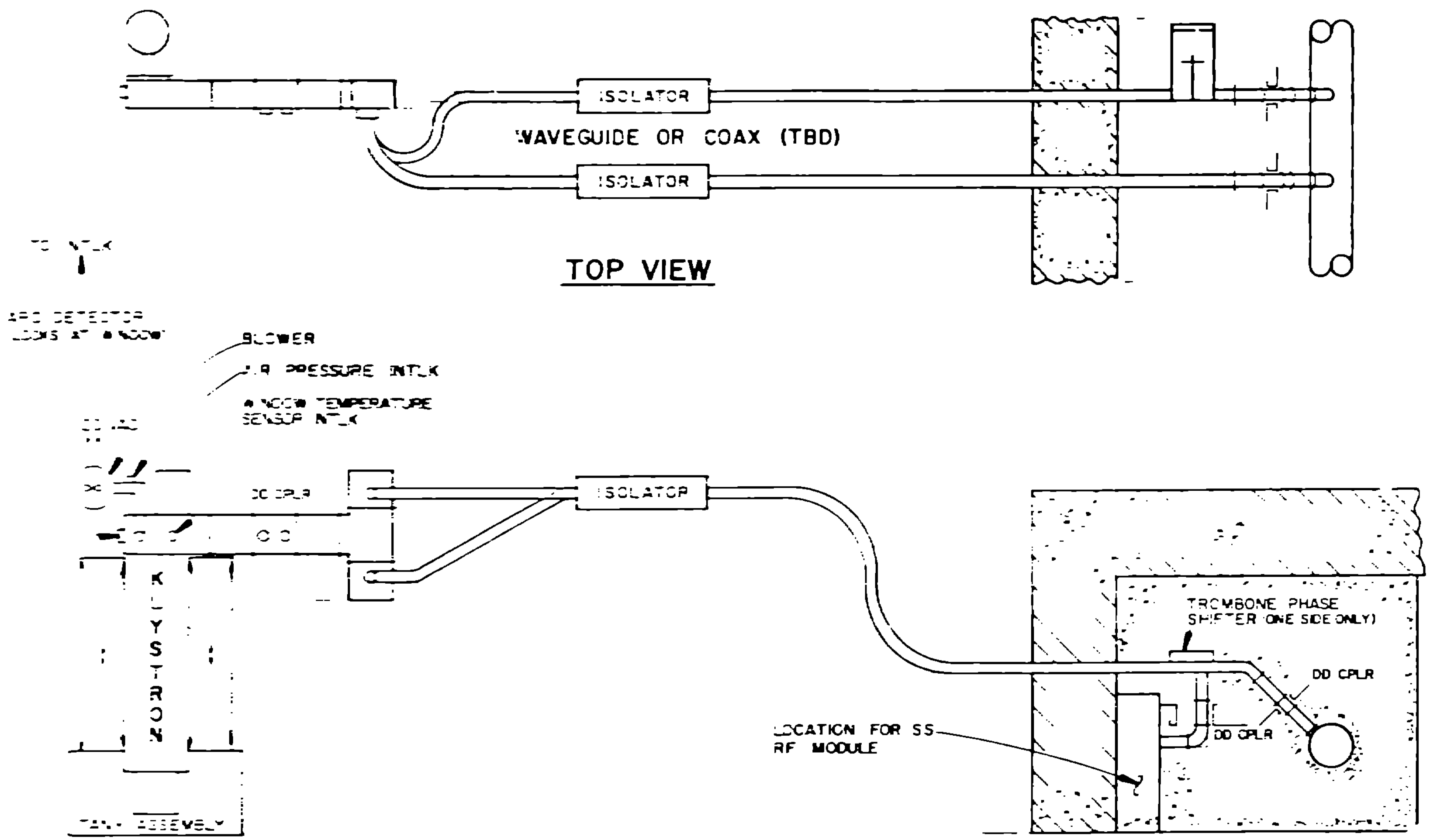
KLYSTRON STATION

- o MODULAR KLYSTRON - MODULATOR PACKAGE
- o LIMITED OVERHEAD SPACE
- o SHIELDING AND GROUNDING CRUCIAL FOR LOW EMI
- o LOCAL AND REMOTE OPERATION POSSIBLE


FRONT VIEW
REAR VIEW
ELECTRONIC CONTROL
& MAG P.S. CABS
WR2100
TRANSITION
KLYSTRON
FOCUS MAGNET
OIL MOVER
WATER MANIFOLD
MODULATOR AREA
REMOVEE INSPECTION
COVER
OIL MONITOR
& OIL HANDLE
HATCH
RAILS
ENTRY
PANEL
10-0" MAX
INTERCONNECTS
AIR OUT
GROUND
CONNECTION
3-0"
12-0" MAX
KLYSTRON OIL TANK
AND MODULATOR
GROUND PLANE
4-9" MAX
GROUND CONNECTION
RF OUT-PUT
WG2100
CONTROL INTERFACE
RACK 1. COMPUTER CONTROL INTERFACE
MAGNET P.S. UNITS, POWER CONTROL.
MEDIUM LEVEL PULSERS, MODULATOR
DIAGNOSTICS, CABINET AIR FANS.
RACK 2. COMPUTER CONTROL INTERFACE
RF DRIVER, RF TIMING GATES AND
TRIGGERS, DIAGNOSTICS, INTERFACES
FIRST FAIL LOCAL REMOTE.
AIR-IN
NOTES:
Los Alamos
KLYSTRON ARRAY
FOR GTA-1 NON BMS VS
ARCHITECTURE
D

FUNCTIONAL DIAGRAM OF HIGH POWER RF STATION



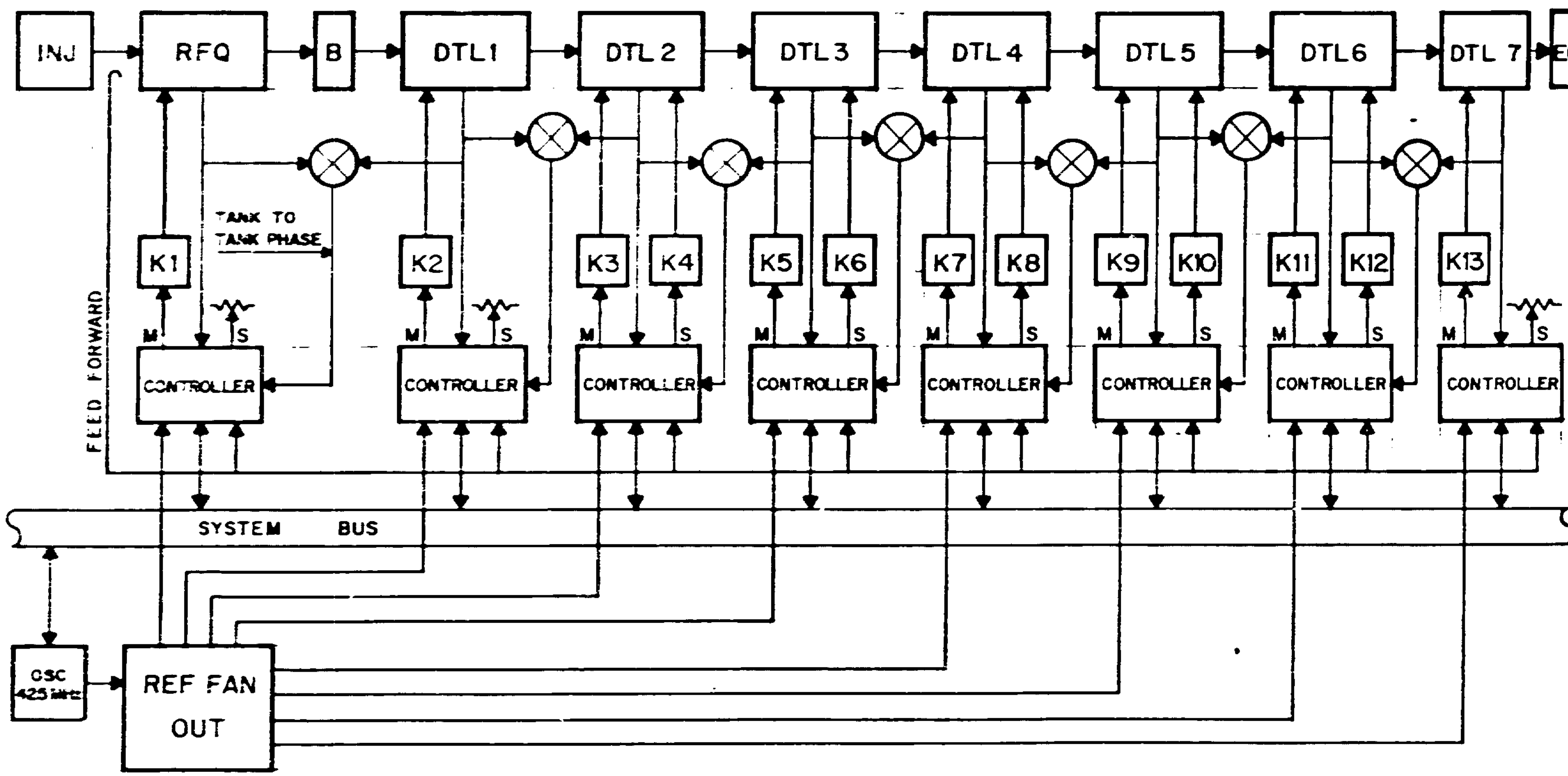


HIGH POWER RF TRANSMISSION SYSTEM

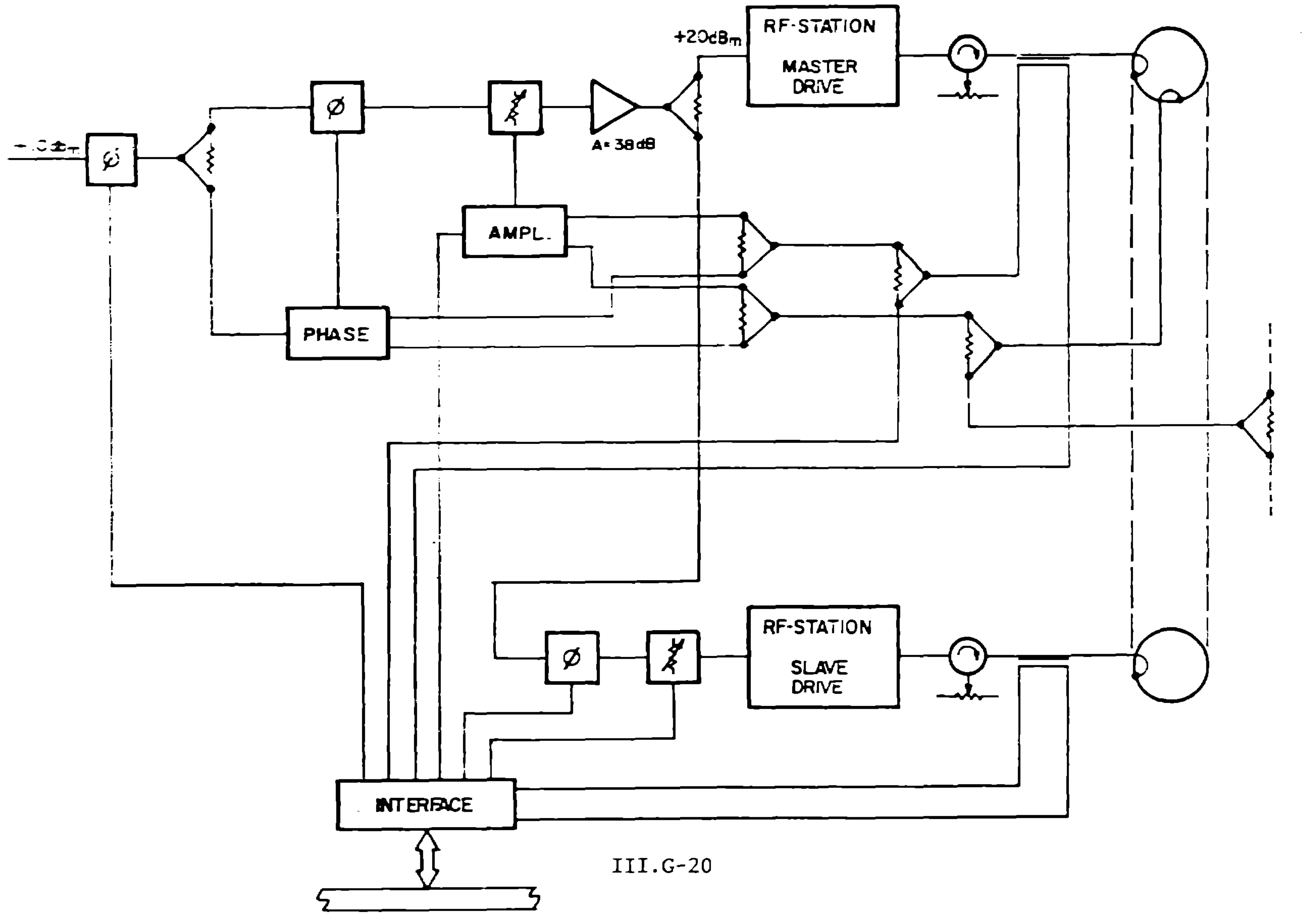
RF DRIVE CONTROL

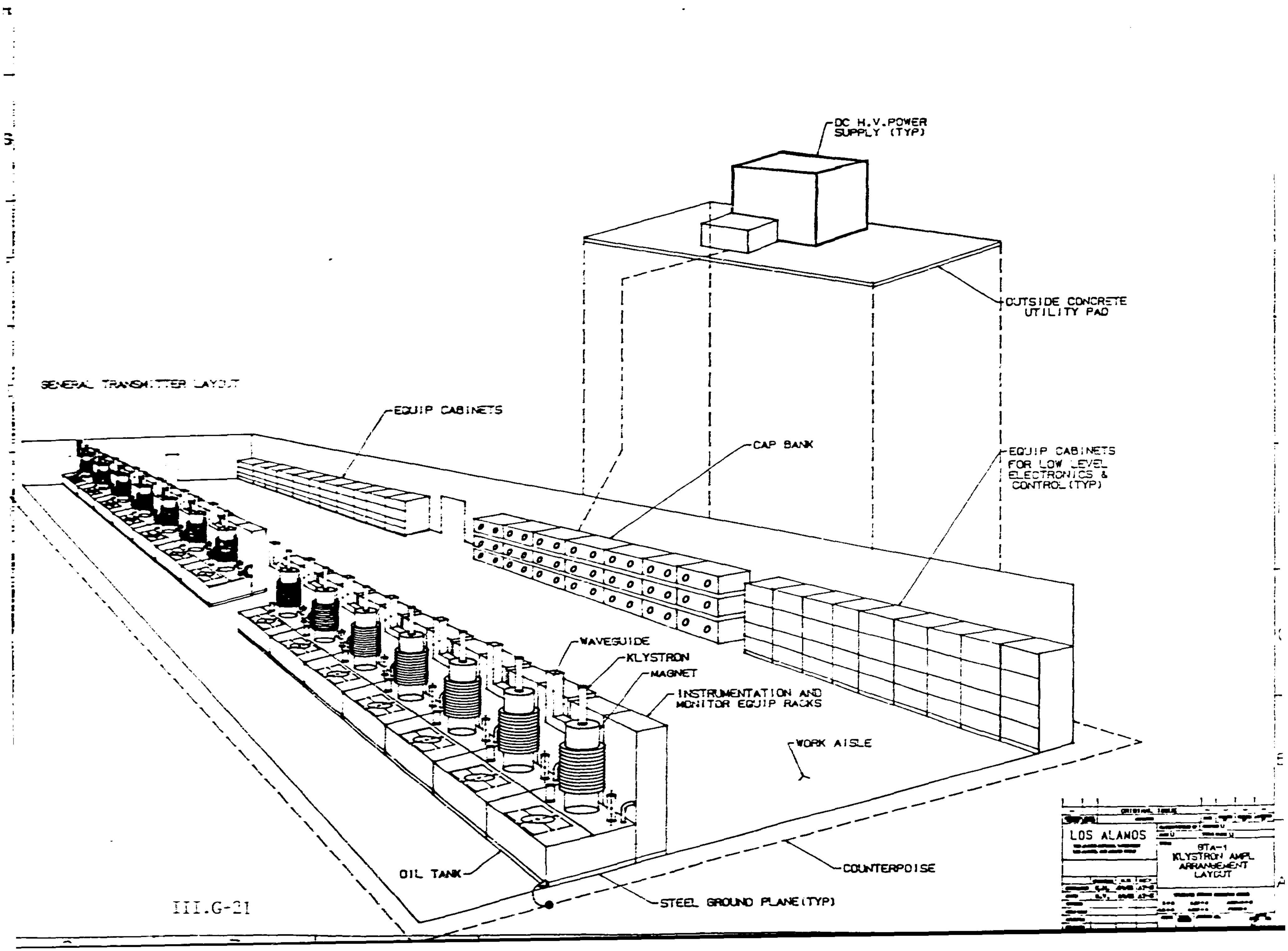
- RF AMPLITUDE AND PHASE CONTROL LOOPS
- DUAL DRIVE SYSTEMS MUST BE SLAVED TOGFTHFR

GTA-1 FUNCTIONAL LOW POWER R.F. & CONTROL DIAGRAM



RF DRIVE & CONTROL
DUAL RF STATION TANK DRIVE





GENERAL TRANSMITTER LAYOUT
DC H.V. POWER SUPPLY (TYP)
OUTSIDE CONCRETE UTILITY PAD
EQUIP CABINETS
CAP BANK
EQUIP CABINETS FOR LOW LEVEL ELECTRONICS & CONTROL (TYP)
WAVEGUIDE
KLYSTRON
MAGNET
INSTRUMENTATION AND MONITOR EQUIP RACKS
WORK AISLE
OIL TANK
COUNTERPOISE
STEEL GROUND PLANE (TYP)
ORIGINAL ISSUE
LOS ALAMOS
BTA-1
KLYSTRON AMPL
ARRANGEMENT
LAYOUT

III.H. INSTRUMENTATION & CONTROLS (I&C)

3.H GTA Control System

3.H.1 Control System Requirements

3.H.2 Subsystem Control Requirements

3.H.3 Control System Architecture

3.H.4 Control System Computer Components

3.H.5 Control System Software Services

3.H.6 Accelerator Beam Diagnostic

3.H.7 Space Compatibility

3.H.8 Status and Schedule

3.H.1. Control System Requirements

Modes of Control: The Control System must monitor and control the accelerator and subsystems during equipment check out, installation, commissioning, and physics experiments. Subsystems must be controlled independently and as an integrated system.

Automatic Control: Control algorithms are required for automatic start-up, maintaining stable operation, recovery from fault conditions, and orderly shutdown of the accelerator components. The algorithms include cold turn-on of the injector, RF conditioning, and magnetic beam alignment through the system.

Operator Interface: The operator interface provides supervisory control of the ground test accelerator from a central location. The current state of the accelerator equipment, alarm conditions and archive data are available to the operator. Scan, alarm, archive, and control parameters can be modified from the operator interface. The operator can configure and save displays at the operator console. The usual guidelines for design of displays – i.e. ease of use, unambiguous and consistent – will be applied to the operator interface.

Data acquisition and Analysis: Accelerator data is acquired for display to the operator. Selected data is archived for analysis by both the operator and the accelerator physicist.

Associated Interfaces: To limit equipment damage and radiation exposure, the *fast protect* system disables the beam within a few microseconds for the remainder of a macropulse. An operator configurable *run permit* system disables the beam until the conditions are cleared. A *timing* system generates and distributes timing pulses for system-wide synchronization.

Fault Conditions: The Control System must respond to fault conditions by logging each occurrence and initiating corrective action, including orderly shutdown or recovery.

Expansion and Changes: The Control System is designed with sufficient modularity to accommodate 100% expansion of I/O channels, memory and CPU time. (4000 channels are estimated for GTA-1).

ISE Prototype Environment: The Control System will provide a prototype environment for the development of control system architecture, control algorithms, characteristic data rates and effective operator interfaces.

- **Modes of Control**
  Supervisory Control (Local and remote)
  Automatic Control (startup, operation, shutdown)
- **Automatic Control**
  Automatic startup, operation, and shutdown
  Automatic fault detection and recovery
- **Operator Interface**
  Local and remote stations
  Display current data, alarms, and historical data
  Manipulate control parameters and algorithms
- **Data Acquisition and Analysis**
- **Associated Interfaces**
  Fast Protect
  Run Permit
  Timing
- **Faults**
  Log each occurrence
  Corrective action
  Correlate with diagnostic data
- **Expansion and Changes - 100% allowance**
- **ISE Prototype Environment**
  Developing Algorithms, Architecture, Data Rates & Operator Interface

3.H.2. Subsystem Requirements

Injector: The Control System must properly startup and operate the injector and perform conditioning on the source. Non-linearities in the parameter space during startup and conditioning may require non-linear control, i.e., open loop sequencing and/or an expert system. There are approximately 150 input/output channels and approximately 20 loops that must be controlled between macro pulses. Most control and data signals must be transferred across a 100 killovolt common mode voltage.

RF Power: The control system must control each RF station both independently and as an integrated system during operation as well as startup and shutdown sequences. Control for RF conditioning, cavity phase, cavity amplitude, resonance, capacitor bank charge voltage setpoint, and macro pulse width is required. Fault detection, logging, and recovery (klystron, waveguide, and cavity arcs, etc.) are required. The local controls must implement extensive diagnostics for the klystron modules. There are approximately 1200 input/output channels in the RF Power Subsystem.

Gas Neutralizer: The neutralizer requires sequence control and interlocking to establish vacuum and regenerate cryopanels. Different alarm limits are used during regeneration and startup. The neutralize has approximately 80 input output channels.

Cooling and Vacuum: Sequence control is required to properly startup and operate the cooling and vacuum systems and to regenerate cryopumps. The RFQ requires ± 0.1°F control over a range of 60°F to 120°F. Other structures require ± 1.0°F control. Cooling and vacuum controls have approximately 1800 input/output channels.

Beam Magnetic Optics: The Control System must provide independent tuning of each segment of the beam transport: HEBT, 180° bend, telescope and steering magnets. Beamline optimization and automatic tuning must also be supported. The Control System must interface to diagnostic devices that measure energy, beam position, emittance and beam current. This subsystem has approximately 780 input/output channels.

Accelerator Beam Diagnostics: The Control System must monitor beam energy, phase, emittance, current, and position at each major accelerator component. It must support ESCAN (injector), vane E measurements (RFQ), EMITTS and LFASE (emittance). The accelerator diagnostics require approximately 800 input/output channels.

Neutral Beam Sensing: Diagnostics interface to control system for beam steering and for physics data.

- **Injector**
  Startup, operation, and source conditioning
  Control and data across 100kV common mode voltage
- **RF Power**
  Startup, operation, RF conditioning
  Provide extensive diagnostics of klystron module
- **Neutralizer**
- **Cooling and Vacuum**
- **Beam Magnetic Optics**
  Control HEBT, 180° bend, telescope, and steering
  Interface to beam transport diagnostics
- **Accelerator Beam Diagnostics**
  Energy, phase, emittance, current, and position
  Receive data from *off-line* diagnostic equipment
- **Neutral Beam Sensing**
  Interface to various sensing and scoring devices
  Provide input for automatic beam steering

3.H.3. Control System Architecture

Accelerator Interface: The interface to the accelerator instrumentation is through CAMAC signal conversion equipment. (IEEE standard 583) Support for the GPIB interface will be provided to support devices which are not supported by CAMAC. (IEEE standard 488)

Input/Output Cluster: The IOC provides data acquisition, closed loop control and sequencing. Each IOC has a control database which contains the parameters needed to scan, alarm, archive and control the accelerator components. Each IOC contains a state transition table which describes the control database parameters for each state of the accelerator subsystem.

Token Bus Network: The Token Bus Network connects the control system components. (IEEE standard 802.4) The Token Bus Network provides the control system components guaranteed access to the network. It transmits at 10 Mbps and has an upgrade path to 80 Mbps.

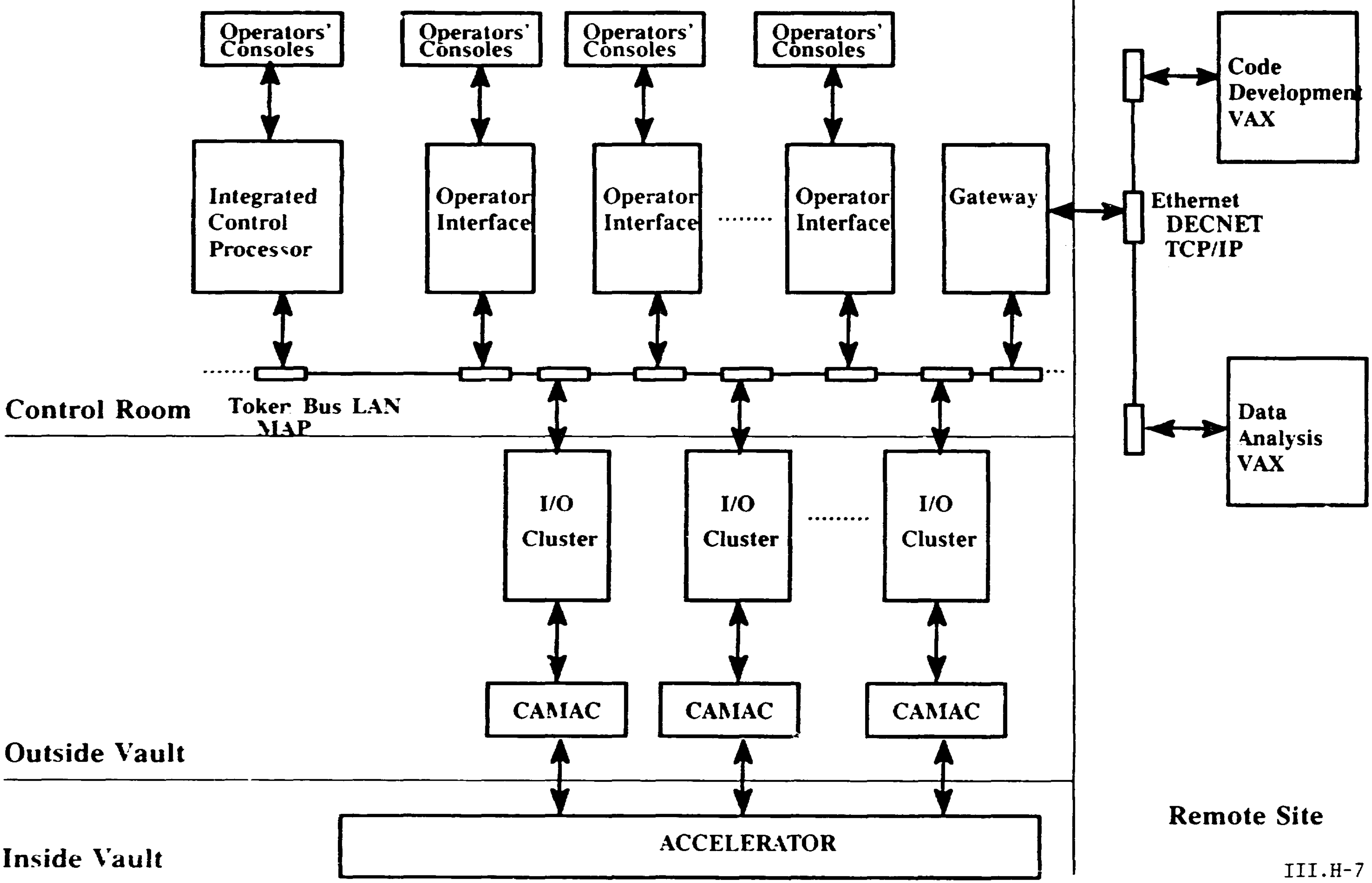
Operator Interface: The OPI receives alarms and archive data generated by the IOCs. It fetches data from the control databases at the IOCs to display to the operator. Alarm and archive data are displayed from the local records. Operator changes to scan, alarm, archive and control parameters are accepted and sent to the control database at the IOCs.

Integrated Control Processor: The ICP is a special case of OPI. In addition to the OPI functions it coordinates the state transitions of all of the control subsystems. This is used for startup, corrective procedures and shutdown. The ICP is also the station at which the displays, control database and state transition tables are configured.

Data Analysis: The experimental data analysis is to run on a VAX to take advantage of the existing beamline codes.

Code Development: The code development is supported on a VAX 750 and a network of Sun workstations.

GTA Control System Architecture



3.11.4. Control System Components

Master CPU Module: The Master CPU module is a VME bus compatible microcomputer. It has a 32-bit address and data computing capability with interfaces to the VME bus and VMX32 bus. The VMX32 bus is a dedicated high performance memory interface. The Master CPU module incorporates a VME bus interface to communicate with other VME bus modules. It is compatible with 32- or 16-bit data, 32- or 24-bit address VME bus compatible devices.

Memory: A dual-ported 1M byte memory module provides the Master CPU with memory access via a private high-speed memory bus. Slave processor units access the same global memory via the VME bus. The private memory port allows higher performance than the VME bus port since it is a dedicated resource to the Master CPU module. The module is expandable to 2M bytes.

System Controller Module: The System Controller module offloads the system-wide functions from the master and slave CPU modules and provides the typical one-per-system type features such as the system clock. This module is also the location of in-system firmware diagnostics.

MAP token-bus Controller: The Manufacturing Automation Protocol (MAP) Network Interface for the VME bus provides the connection between the IEEE-802.4 standard network and the Master CPU module. The MAP network interface includes a 10 Mbps MODEM and is implemented on a two board set. The MAP network interface handles token-bus protocols with MAP 2.1 compatible hardware and software.

Serial Controller: This module provides an interface between the VME bus and serial communication devices. It contains a complete slave microcomputer to relieve the Master CPU module from serial communication tasks. Data pre- and post-processing, insertion and deletion of control information, error detection and flow control are typical tasks which this slave processor can perform.

Disk Controller: A Winchester disk controller provides an interface to a 40 M byte hard disk drive. The disk controller permits the addition of a second drive if required. The disk controller is used in the OPI and ICP and is an IOC option.

Display Controller: A high resolution (1600 X 1280 X 4) graphics display controller provides an interface to a color raster display. The full Graphics Kernel Standard (GKS) is supported in firmware.

CAMAC Interface: The VME-to-CAMAC interface is a hardware module which allows a CAMAC parallel branch highway to be driven from the VME bus. Up to seven crates can be accessed from a single controller. This module works in conjunction with a second module which permits DMA transfers to be made from CAMAC to VME.

GPIB Controller: The General Purpose Interface Bus (GPIB) controller provides support for instruments using the IEEE-488 interface bus for automated instrument control. This module can be thought of as a bus translator, converting messages and signals present on the VME bus into appropriate GPIB messages and signals. The GPIB controller is an IOC option and is implemented as required.

VME Hardware Components

- Master CPU Module
- Memory
- System Controller Module
- MAP Token–Bus Controller
- Serial Controller
- Disk Controller
- Display Controller
- CAMAC Interface
- GPIB Controller

3.H.5. GTA Control System Software Services

General Services: Each node will contain software for general services: network communications over the token ring, interface to a serial port, down-line loading support, system monitoring and diagnostics.

Operating System: The VRTX operating system (Hunter & Ready Inc.) is used as the real-time operating system. The VRTX kernal is ROM resident and performs real-time requests very efficiently. VRTX provides intertask communication, real-time task context switching, I/O support and a file management system.

IOC Services: The IOC software supports the CAMAC and GPIB interfaces which interface the Control System to the Accelerator. It provides the data acquisition, alarm generation, data archiving and first level control. The IOC accepts operator requests from the OPI and ICP to alter setpoints, outputs and state transitions. Operator display requests are serviced at the IOC to provide operator display data for the OPIs and the ICP.

OPI Services: The OPI software provides the operator with data from the IOCs for display. It accepts operator requests to change setpoints and outputs, and states and sends them over the network to the IOCs. The OPIs maintain the current alarm regions and the archived data transmitted from the IOCs.

ICP Services: The ICP software provides the operator with data from the IOCs for display. It accepts operator requests to change setpoints, outputs, and states and sends them over the network to the IOCs. The ICP maintains the current alarm regions and the archived data transmitted from the IOCs. The software for building operator displays, process databases and state transition tables is resident on the ICP.

Gateway Services: The Gateway software provides an interface between the Control Network and the development and analysis machines. It services requests from the development system to down-line load tasks to the Control System nodes. The Gateway also services requests from the data analysis machines to transmit archived data from the OPIs and the ICP.

GTA Control System Software Services

- General Services
- Real-Time Operating System
- IOC Services
- OPI Services
- ICP Services
- Gateway Services

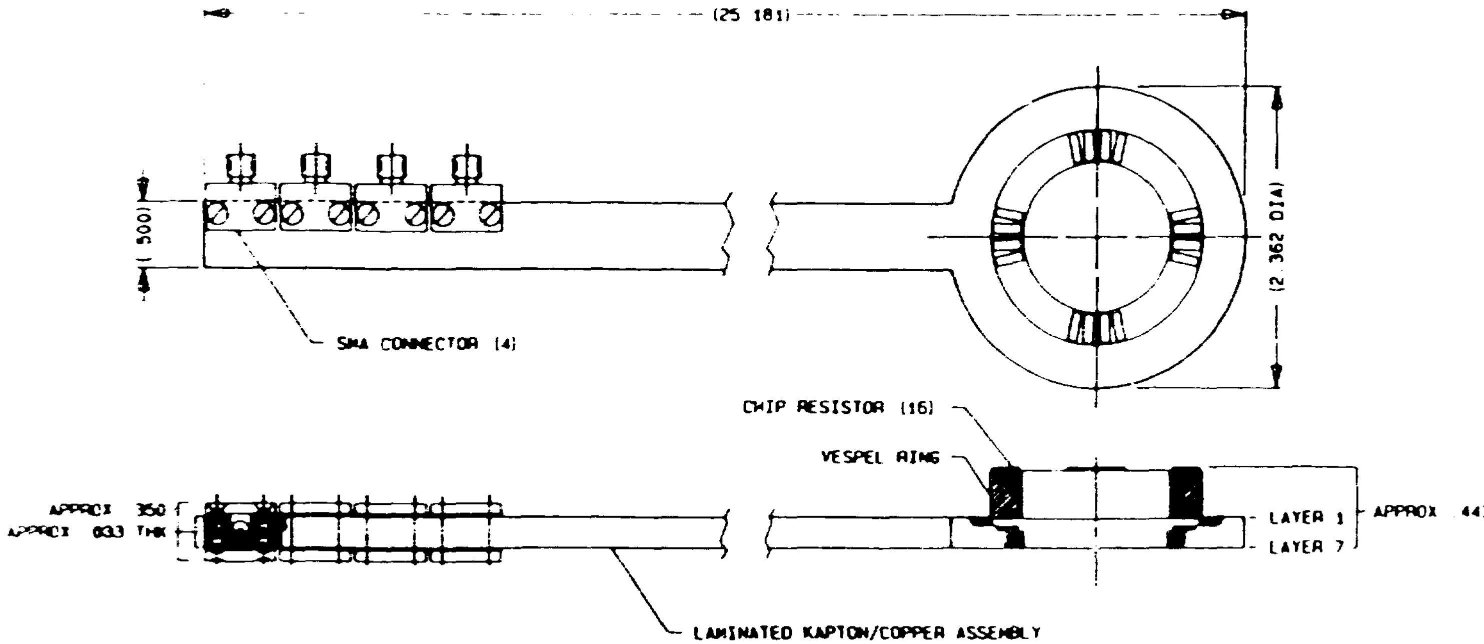
3.H.6. Accelerator Beam Diagnostics

Microstrip Probes: Microstrip probes, installed inside drift tubes and at other locations throughout the beamline, measure energy, average and peak beam current, beam transverse position, beam synchronous phase, and *possibly* beam second moments. RF signal processing converts the high-bandwidth signals to signals that can be easily monitored by the Control System and sampling oscilloscopes.

Each microstrip probe is made up of a seven-layer kapton/copper assembly. The four outputs from the stripline are connected to RF signal processing. The resulting waveforms are amplified and filtered for interfacing to the Control System.The Control System can sample each output signal once during each macropulse.

Other On-line Diagnostics: Faraday cups, wire scanners, and harps will be used. The location and quantity of these devices has not yet been determined.

Offline Diagnostics: The control system will receive data from various offline diagnostics (ESCAN, EMITS, LFASE, etc.). This interface has not been defined.



LOS ALAMOS

LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO 87545

MICROSTRIP ELECTROMAGNETIC PROBE ASSY

GTA

112Y-253213

3.H.7. Space Compatibility

Goals for Automatic Control: Our goal is to develop algorithms for automatic control that will implement startup and shutdown of all subsystems, maintain a selected operating point, and provide automatic fault handling, including fault recovery. The specific areas where automatic operation is significant are (1) the Injector, especially during startup; (2) RF conditioning of the RF waveguides and cavities; and (3) beam optics tune up.

Hardware: Although the Control System hardware is not space qualified, there is nothing to preclude adapting the architecture to space.

Software: All software will be modular and, wherever practical, all processor and operating system dependencies will be isolated to a few modules. The operating system is "flight" qualified by the FAA.

Space Compatibility

- Goals for Automatic Control
  - Startup and Shutdown of all subsystems
  - Maintain a selected operating point
  - Automatic fault recovery
- Hardware
  - Not space qualified
  - Architecture is adaptable to space
- Software
  - Modular Code
  - Processor–independent
  - Operating system is “flight” qualified

3.H.8 Status and Schedule

Hardware: The hardware architecture and major VME bus modules have been selected. Selection of the remaining VME bus and input output components will be completed as needed. A local operator interface capability will be developed first, followed by a more extensive design for the central control room.

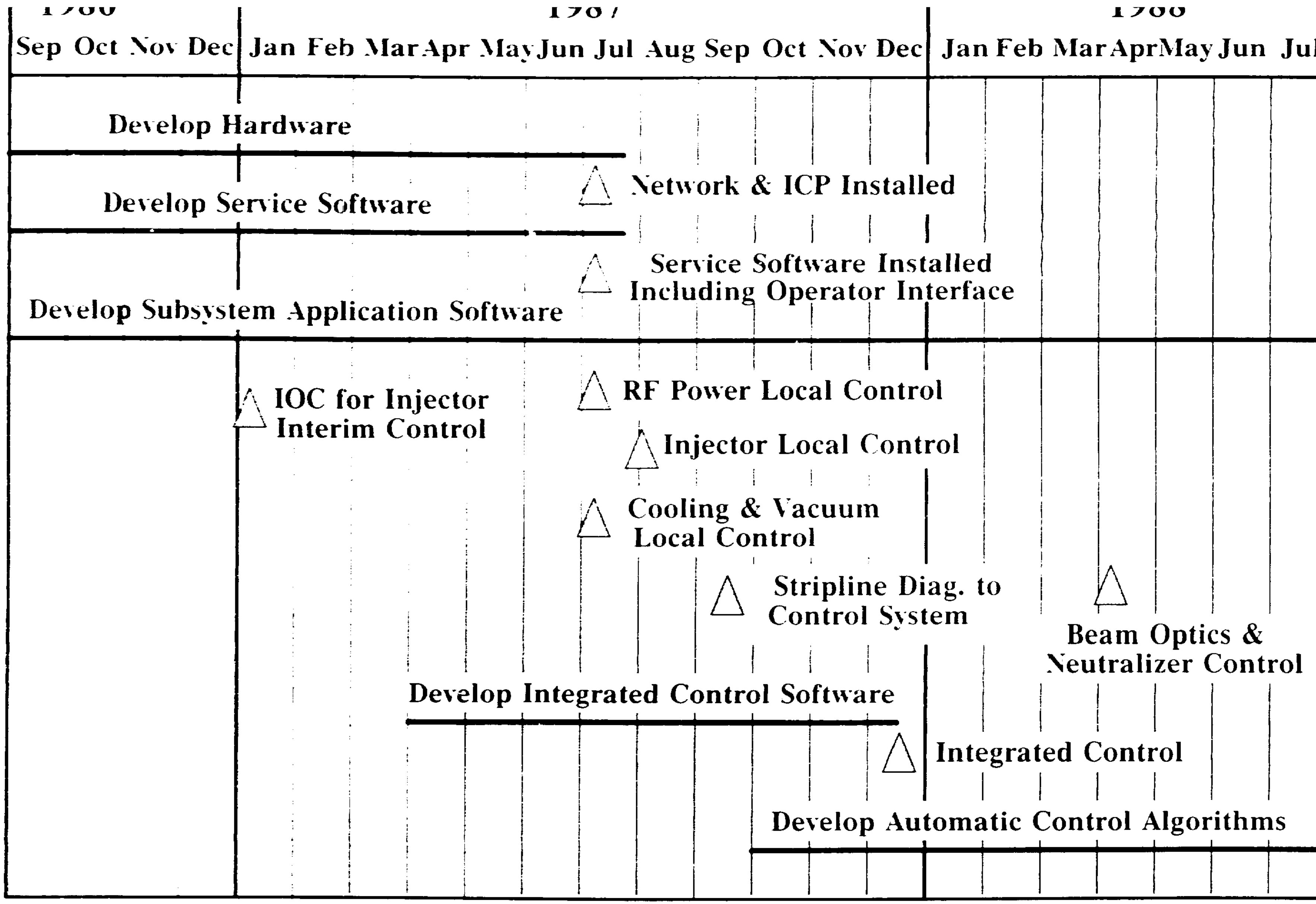
Service Software: Service software includes input output drivers, operator interface tasks, interprocessor communications, real-time data base structure, and routines to down load and initiate the applications tasks. This software is needed to support applications.

Applications Software: Applications software will be developed to support the various subsystems. Modifications to this software are expected throughout the GTA lifetime.been sufficiently specified.

Integrated Control Software: Integrated control software is needed to commission the accelerator and conduct physics experiments.

Automatic Control Software: Automatic control algorithms will be developed concurrently with the commissioning and experimental phases of GTA.

Injector Interim Control: A stand-alone control capability will be provided for experiments on the injector before it is installed in the GTA facility. This will include Injector control software, a standard IOC, and appropriate service software.


Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
Develop Hardware
Network & ICP Installed
Develop Service Software
Service Software Installed Including Operator Interface
Develop Subsystem Application Software
RF Power Local Control
IOC for Injector Interim Control
Injector Local Control
Cooling & Vacuum Local Control
Stripline Diag. to Control System
Beam Optics & Neutralizer Control
Develop Integrated Control Software
Integrated Control
Develop Automatic Control Algorithms

III.I. Process Cooling

III. I. PROCESS COOLING

GTA-1 Cooling System

The function of the cooling system is to remove all excess heat from the NPB device components generated during system operation and transfer this heat to the cooling tower. The design of the cooling system will incorporate personnel safety and equipment reliability as paramount considerations. The secondary cooling loops use de-ionized water for heat removal and transport. Certain components such as the RFQ, DTL and part of beam sensing must be thermally controlled to very tight tolerances that are far above industry standards. These will require multiple piping systems with special mixing valves and controls. Each of the remaining components has distinct requirements which must be met in the areas of heat load, flow rates, water quality, pressure range, pressure surging and temperature range. These requirements, where they have been defined, are for the most part within industry standards. The exceptions being at the H^- beam stop and three beam stops at the end of the accelerator where water activation will impose additional equipment and safety concerns.

In addition to the system design, the procurement, installation and operation of GTA-1 will be covered by the cooling system. Three major concepts will be applied to the system whenever possible:

1. Safety
2. Maximize machine availability
3. Ease of maintenance and operation

GTA-1

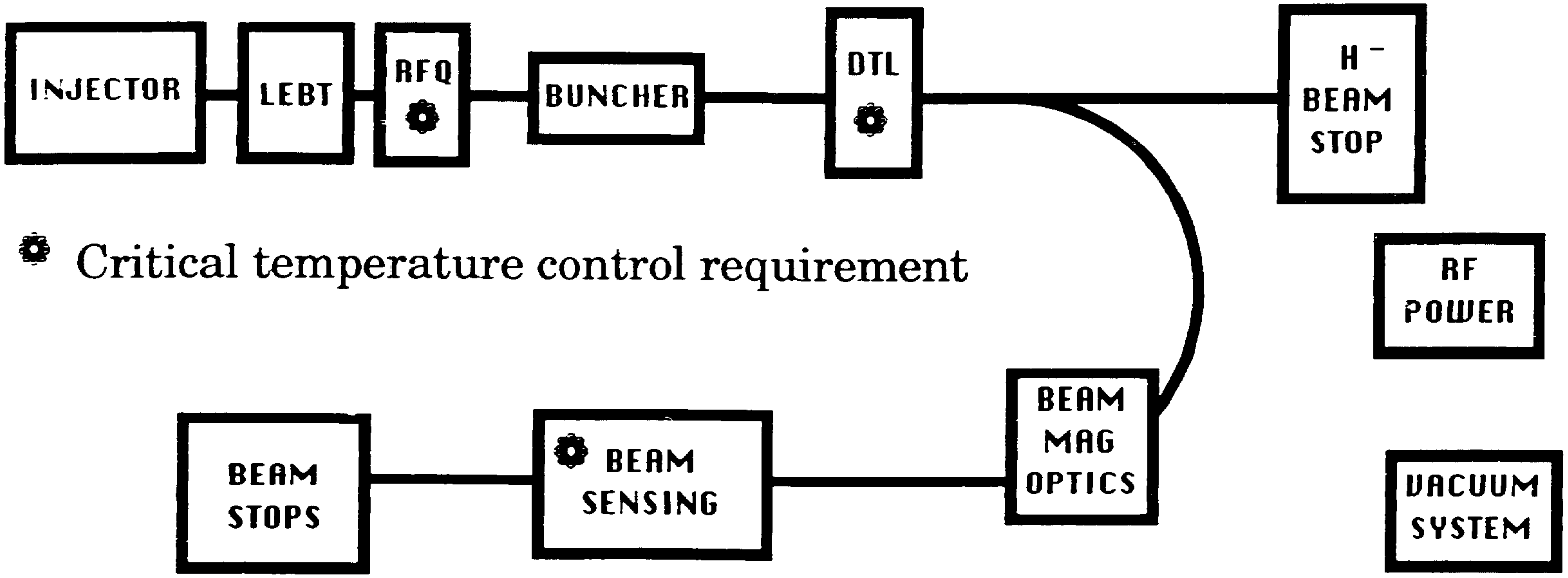
COOLING SYSTEM OBJECTIVES

- Design
- Procure
- Install
- Operate
- Ease of Maintance & Operation
- Maximize Machine Availability
- Personnel Safety

Eleven components of GTA-1 have been identified as having cooling requirements. These components have 23 distinct cooling needs. A list of these components, by system number, is on the next Vu-graph.

The components of GTA-1 fall into three general catagories:

1. Components whose cooling requirements fall within industry standards: injector, LEBT, beam magnetic optics, beam sensing, RF power, vacuum system and buncher.
2. Components where water activation will impose additional safety concerns: H^- beam stop and three beam stops at the end of the accelerator.
3. Components that require critical temperature control: RFQ, DTL's and beam sensing-laser diagnostics.



11 components of GTA-1 have been identified that require cooling.

GTA Phase 1

Cooling System

Requirements

The condensed table shown below is a summary of preliminary design information on the 11 components of GTA-1. The information has been condensed for the purpose of presentation and is not directly applicable to outside design. More detailed and extensive information on the 23 individual requirements is in the cooling system design package.

Component	Nominal Heat Load (KW)	Temp Inlet Temp (°F)	Nominal Control Range (°F)	Inlet Pressure (psi)	Flow Rate (GPM)	Comments
1. INJ	15	70	± 5	N.R.	30	
2. LEBT	1	70	± 5	N.R.	5	
3. RFQ	1.5	*	± 0.5	50 to 60	50 to 160	
4. BUN	Minimal	72.5	± 0.5	30	(5)	
5. DTL	12	72.5	± 0.5	50	50 to 175	
6. BMC	(20)	70	± 5	125	4 to 15	
7. H(-)B.S.	5	70	± 5	(125)	150	Activated Water
8. BEAM SX	(5)	70	± 3	(100)	(5 to 15)	
9. BEAM STOPS	(7)	70	± 5	(125)	(250)	Activated Water
10. VAC	40	70	± 10	50	75	
11. RF PWR	98	70	± 5	100	175	

Values in parenthesis were estimated by Cooling System.

*Water temperature is used to tune RFQ and is predicted to be in the range of 55 to 90 °F.

Cooling System Loops

This table lists the 23 individual components that require cooling

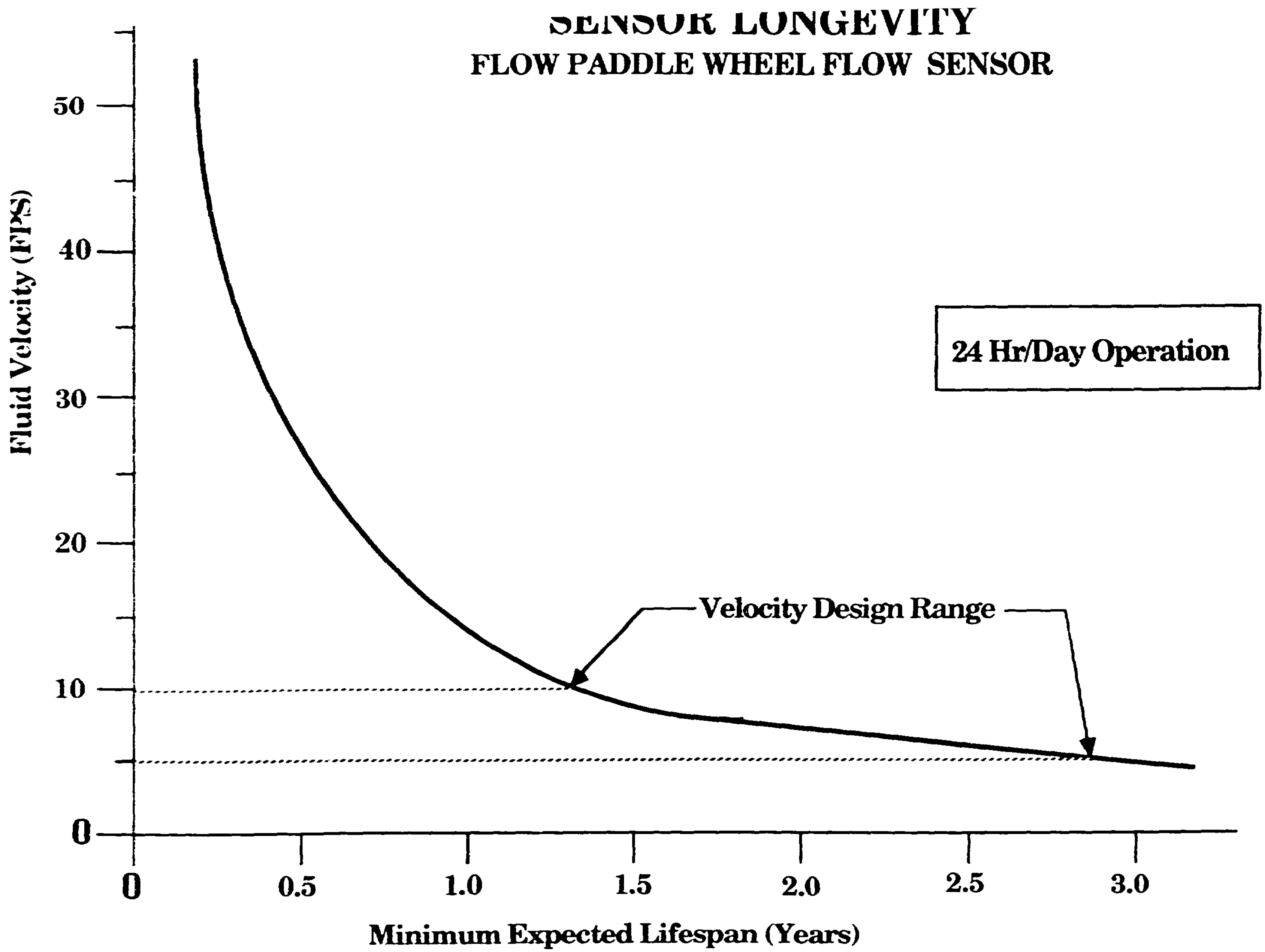
System 41	System 42	System 43	System 44 ✿	System 45 ✿
Injector Source	RF Power	H(-) Beam Stop '1'	DTL Drift Tubes	RFQ Tip
LEBT		H(+) Beam Stop	DTL Tank	RFQ Structure
Beam Mag Optics - 180 Bend		H(0) Beam Stop	Buncher	
" " " - Beam Exp		H(-) Beam Stop '2'	Beam Sensing - Laser Diagn.	
" " " - Match Sect		Located at end of accelerator.		
" " " - Steering Mag				
" " " - Momentum Compactor				
Beam Sensing - Sweeping Mag				
" " - Mech Sensing Equip				
Vacuum System - Cryo				
" " - Turbo				
RFQ RF Drive Loop				

✿ Critical temperature control requirement

Basis of Design

The following information is a condensed list of the cooling system criteria .

- Flow velocities to be kept in the range of 5 to 10 fps (feet per second) with 7 fps being the nominal design.
- Design system for continuous operation to eliminate start-up and shut-down time.
- Use of modular design and prefabrication.
- Water quality that will be compatible with copper, aluminum and stainless steel is planned. This will probably be de-ionized (DI) in the range of 1 to 2 MΩ cm with a pH of 8 to 9. An isolated system will be used for carbon steel components.
- Pressure pulsation will be controlled, where requested, with nitrogen charged accumulations in the range of 5 psig or TBD Hz (possibly in the area of 10 Hz).
- Instrumentation and Control - since the cooling water is an auxiliary system, it is not required to be fully automatic. The cooling system will be designed so it can be computer controlled during the run mode.
- Definition of line burst and equipment failure procedures will be specified. These systems will probably be a hard-wired type as opposed to computer controlled, and will most likely employ pressure switches on a "Fail-Safe" circuit.
- System is designed for 0.1% Duty Factor with provisions being made for 5% Duty Factor on conditioning and running RFQ and DTL in a test mode.
- Cooling system to be designed to maximize accelerator availability while providing ease of maintenance and operation.
- To keep personnel safety as a paramount issue in system design.


SENSOR LONGEVITY
FLOW PADDLE WHEEL FLOW SENSOR
24 Hr/Day Operation
Velocity Design Range
Fluid Velocity (FPS)
50
40
30
20
10
0
0
0.5
1.0
1.5
2.0
2.5
3.0
Minimum Expected Lifespan (Years)

INSTRUMENTATION & CONTROL

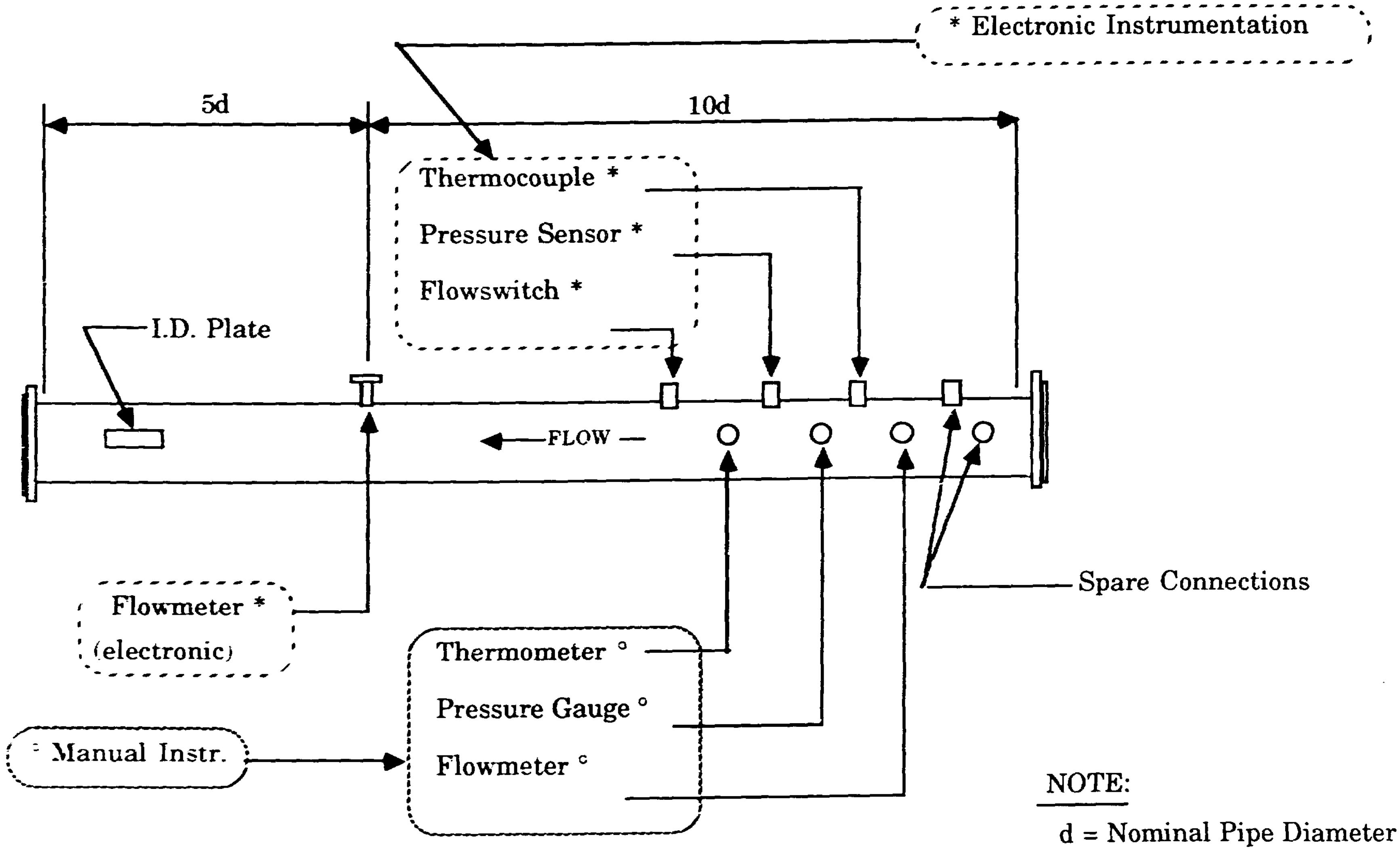
A "Dual Sensing" approach will be used in most cases via a "Modular Water Monitor".

The instrumentation on the water monitor using the dual sensing approach will be of two types:

1. Electronic - which will have remote computer read out available in the operations room.
2. Manual - which will allow local inspection of fluid conditions at or near the component being cooled.

All or part of the sensing instrumentation on the monitor may be used as necessary. Additional contingency taps will be provided, while all unused taps will be capped or plugged. The instrumentation devices will plug into the water monitor using "wet tap" connections. This will allow the sensing instruments to be inserted or removed without system shut-down.

COOLING SYSTEM
"Modular Water Monitor"



Critical Temp Control is necessary for cooling system #44 and #45 of GTA-1.

In system 44 the drift tube linac (DTL) requires a stable temperature environment of $\pm$ 0.5° F in order to keep slug tuners from excessive wear and within their operating range.

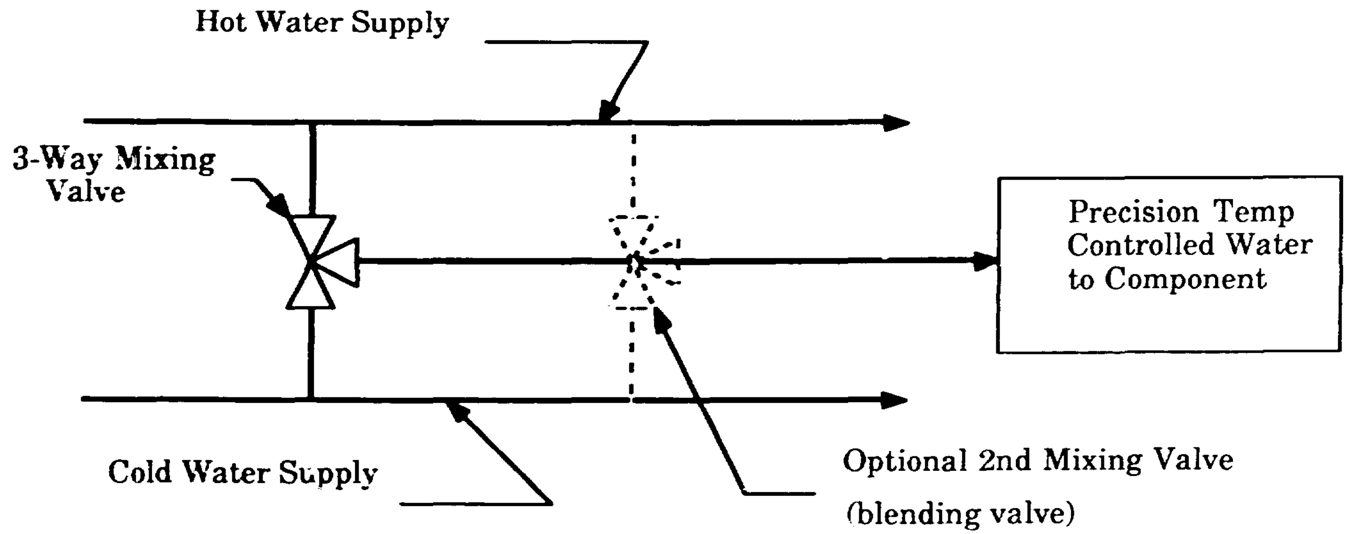
Also in system 44, the beam sensing-laser diagnostic area will require cooling water in the temperature range of 60 to 75° F which must be controlled to $\pm$0.5° F.

System 45 has been dedicated to the RFQ, once it has been machined and set in place, the only way provided to fine tune it is via cooling water temperature. The operating temperature band predicted for the RFQ is expected to lie between 55 to 90 °F. Once the proper operating temperature is selected, it must be maintained within $\pm$0.5 °F or better.

Critical Temp Control

Precise control of water temperature is planned via a 3-way mixing valve system as shown below.

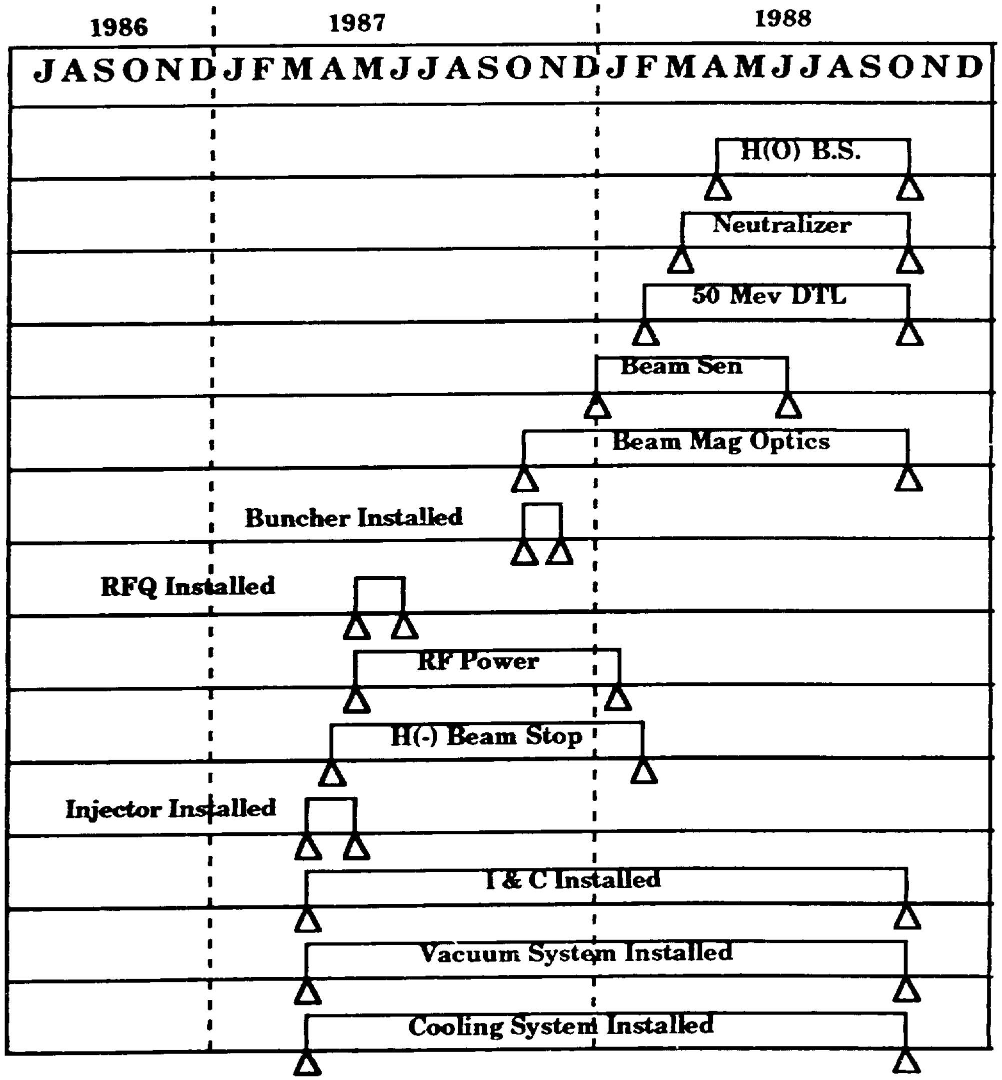
The system shown below is a simplification since the "Hot Water Supply" and "Cold Water Supply" can be only a few degrees above and below the temperature which the component requires.



Build-Up and Installation

One of the keys to the success of GTA-1 will be the coordination of the installation of the various accelerator components with their subsystems. The goal of the cooling system is to be ready with cooling water when the various components need it. The installation schedule that follows is what we are currently working toward.

Build-Up & Installation



III.J. VACUUM SYSTEM

III.J. VACUUM SYSTEM

III. J. VACUUM

1. GTA Vacuum System; Requirements, Goal And Approach

The requirement of the vacuum system is to maintain certain pressure levels (generally 10^{-6} torr or less) in the various component sections of the machine.

A specific goal, to be sought after in the design of the vacuum system, is to maximize machine availability by paying particular attention to those aspects of vacuum systems that are time consuming. Leaks tend to produce the greatest delays in operating large vacuum systems, but the effects of leaks can be mitigated by localizing and leak checking quickly.

Accordingly, the design of the GTA-1 vacuum system utilizes beam line valves that can be used to isolate leaks or outgassing to a small section of the machine and a vacuum pumping and instrumentation selection that permits quick change out and leak checking of components.

GOAL

:Maximize Machine Availability

APPROACH

:Section Machine With Beam Line Valves

:Each Section Can Go From Ambient Pressure to High Vacuum Quickly

:Each Section Can Be Helium Leak Checked Quickly - All Sections Also Have Residual Gas Analyzers

2. The Approach Is Effected With A Combination Of Cryopumps And Turbopumps

Turbomolecular pumps, as used on GTA-1, are capable of quick start up, can pump all gases, and can assist with leak detection by boosting the tracer gas pressure in the pump foreline.

Residual gas analyzers provide an indication of which gases are present in the system and the percent contribution of each gas to residual pressure. Analysis of the spectrum quickly categorizes pumping problems according to in-leakage or outgassing and, if outgassing, what particular type.

Cryopumps offer economy and cleanliness and pump the bulk of gases in GTA-1. However, they do not pump helium well and are not useful for leak detection.

Local control allows subsystem testing independent of other machine sections.

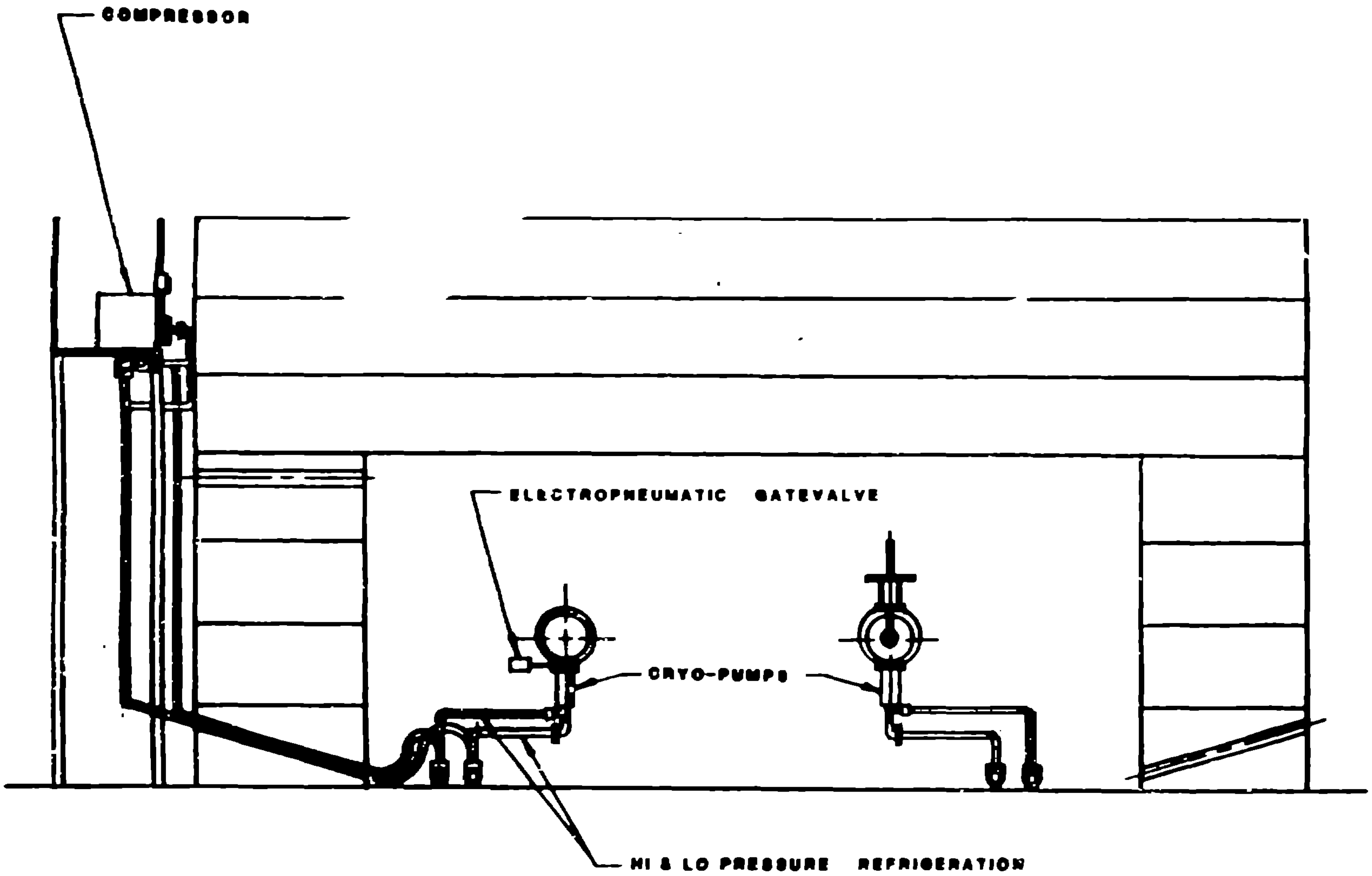
Beam operation is facilitated by computer cognizance of the status of all pressures, pumps, and valve positions.

Damage to pumps and oil backstreaming from roughing pumps into the machine is precluded by hard-wired protection circuits that prevent direct roughing pump paths into the machine at low pressures without correct turbopump operation.

DESIGN	:EACH SECTION HAS A TURBO-MOLECULAR PUMP AND BACKING PUMP SIZED FOR QUICK (LESS THAN 30 MIN.) PUMP-DOWN
	:EACH SECTION HAS FORELINE CONNECTIONS FOR HELIUM LEAK DETECTORS
	:ALL SECTIONS HAVE RGA HEADS PERMANENTLY INSTALLED
	:MAIN HIGH VACUUM PUMPING IS BY APPENDAGE CRYO-PUMPS
	:LOCAL CONTROL OF PUMPS, VALVES, GAUGES AND ANALYZERS
	:CENTRAL SURVEILLANCE OF PUMPS, VALVES AND PRESSURES
	:HARD-WIRED PROTECTION CIRCUITS SHUT VALVES AND PUMPS IN THE EVENT OF OVER-PRESSURE

3. Placement Of Components

The cryopumps and turbopumps are mounted to gate valves that are bolted to the underside of the machine. High pressure helium gas, used to cool the cryopumps, is routed from compressors through passages in the shielding to the pumps. Cables, used to power the turbopumps, pass from local electronics racks through the same passages in the shielding to the pumps. By keeping supporting equipment out of the vault, valuable floor space is saved and maintenance on compressors and turbopump power supplies is greatly facilitated. Two cryopumps are run from a single compressor, which reduces the high pressure helium piping at an acceptably small reduction in system reliablility.

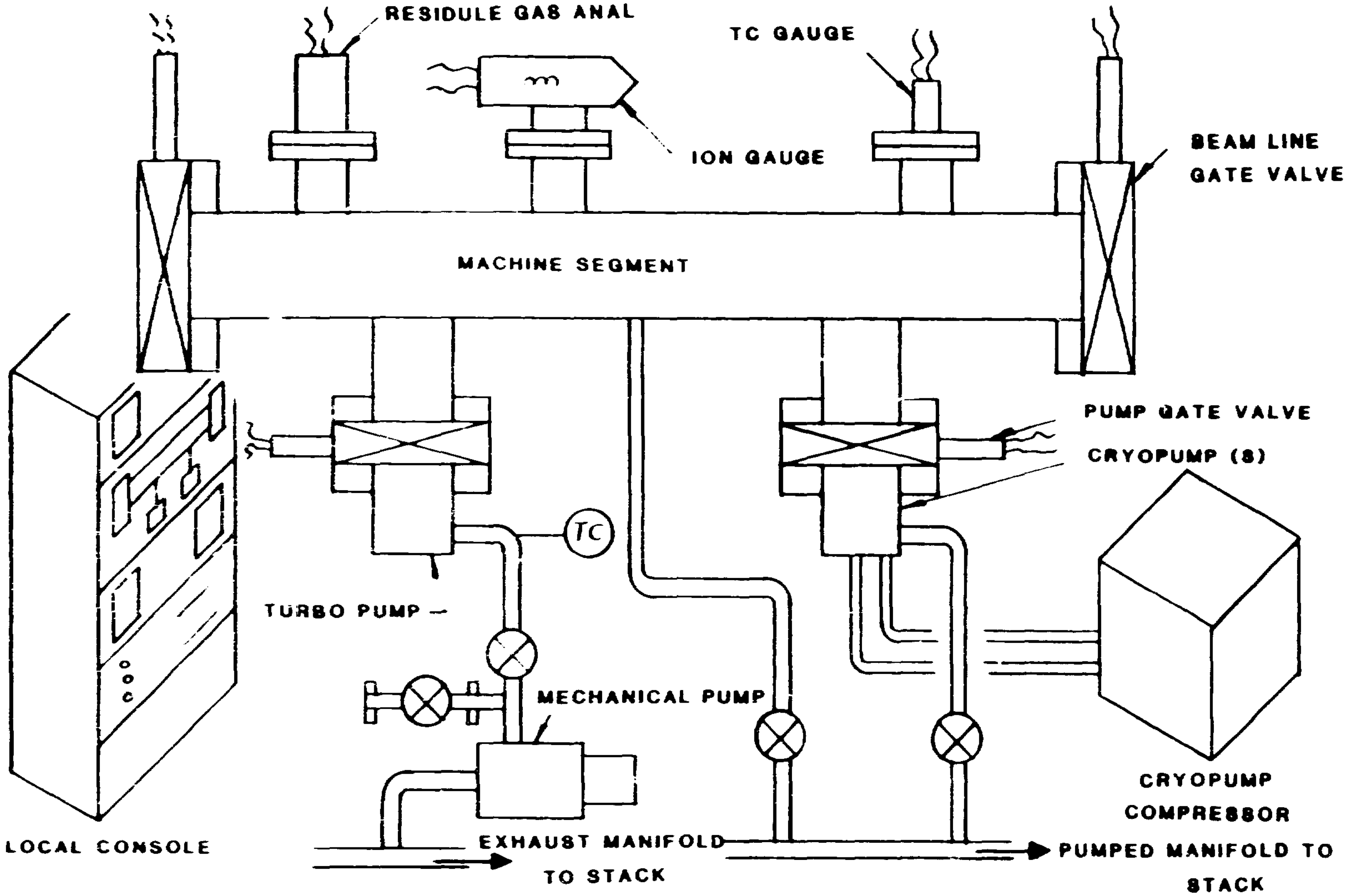


REFRIGERATION PIPING

4. Several Independent Systems Comprise The GTA-1 Vacuum System

Machine assembly and check-out is facilitated by separate vacuum systems that come on-line as the machine is assembled. This "stand-alone" capability allows pump out from atmospheric pressure, leak detection, residual gas analysis, cryopump regeneration, and pressurization of the machine segment with an inert gas.

When the machine is fully assembled, these separate vacuum systems permit quick localizing of leaks and outgassing problems and allow changes and repairs to be made with minimum impact on the remainder of the machine.



EACH MACHINE SEGMENT WILL HAVE AN INDEPENDENT VACUUM SYSTEM

5. Sizing The Number And Diameters Of The Pumps

To size the number of pumps to be used on GTA-1, conservative offgassing and permeation coefficients were used. In the injector and beamstops, hydrogen is the predominant gas load. In the gas neutralizer and neighboring beam sensing and telescope section, argon, the neutralizing gas, dominates. Spillage from the neutralizer into the beam sensing and telescope sections limits vacuum levels attainable in these areas to the low 10^{-5} torr region.

Eight-inch nominal diameter pumps are capable of pumping anticipated gas loads in the accelerator sections with a minimum impact on rf shielding and cooling configurations. To simplify the design, and for operational and maintenance considerations, eight inches was made the standard pump diameter for the majority of GTA-1. Exceptions are the injector and beamstops where high hydrogen loads mandate the use of larger, ten-inch diameter pumps.

SUMMARY

SECTION	GAS LOAD	PUMPS
Injector	H_2~3000 l/s AT 10^{-5}, 100 sccm AT 10^{-2}, (250 cfm)	(2) RCP 321 CRYO = 6400 l/s (1) WSU 1000 BLOWER 450 cf
RFQ	160 l/s PERMEATION & OFFGASSING AT 10^{-6}	(2) CT 8'S = 1680 l/s (1) LH 1000 AT 650 l/s
LINAC (1 OF 7)	650 l/s PERMEATION & OFFGASSING	(2) CT 8'S AT 350 l/s (1) LH 1000 = 307 l/s
MATCHING SECTION	MODERATE OFFGASSING	(1) CT 8 = 840 l/s (1) LH 1000 =650 l/s
H (-) BEAM STOP	H_2~3000 l/s AT 10^{-6}	(1) RCP 321 CRYO 4000 (1) LH 1000 = 650 l/s
180 DEGREE BEND	MODERATE OFFGASSING	(2) CT 8'S = 1680 l/s (1) TURBO = 650 l/s

SUMMARY

SECTION	GAS LOAD	PUMPS
TELESCOPE	ARGON .16 tl/s	(10) CT 8'S = 8400 l/s (1) LH 1000 = 650 l/s
NEUTRALIZER	.109 g/s ARGON	CRYOPANELS (1) LH 1000 TURBOPUMP = 650 l/s (1) BLOWER
BEAM SENSING	ARGON≈.16 tl/s	(10) CT 8'S = 8400 l/s (1) LH 1000 = 650 l/s
H(O) BEAM STOP	H_2≈3000 l/s AT 10^{-6}	(1) RCP 321 CRYO = 4000 l/s (1) LH 1000 = 650 l/s

6. Component Summary

The total GTA-1 vacuum system includes 37 eight-inch-diameter cryopumps and 16 eight-inch-diameter turbomolecular pumps. Rough pumping of most machine sections is effected with the rotary vane mechanical pumps, which also back the turbomolecular pumps.

For high pressure conditioning of the injector, a Roots blower and mechanical pump combination is used: for rough pumping of large volumes in the beam sensing, neutralizer and telescope sections a large Roots blower and two rotary piston pumps are used.

Ten-inch cryopumps were selected for the large hydrogen loads in the injector and beamstops.

Instrumentation includes ionization and thermocouple gauges and two residual gas analyzers (RGA's). The RGA'S have a switching arrangement that permits analysis of heads located in 16 locations on the GTA-1.

GRAND TOTAL

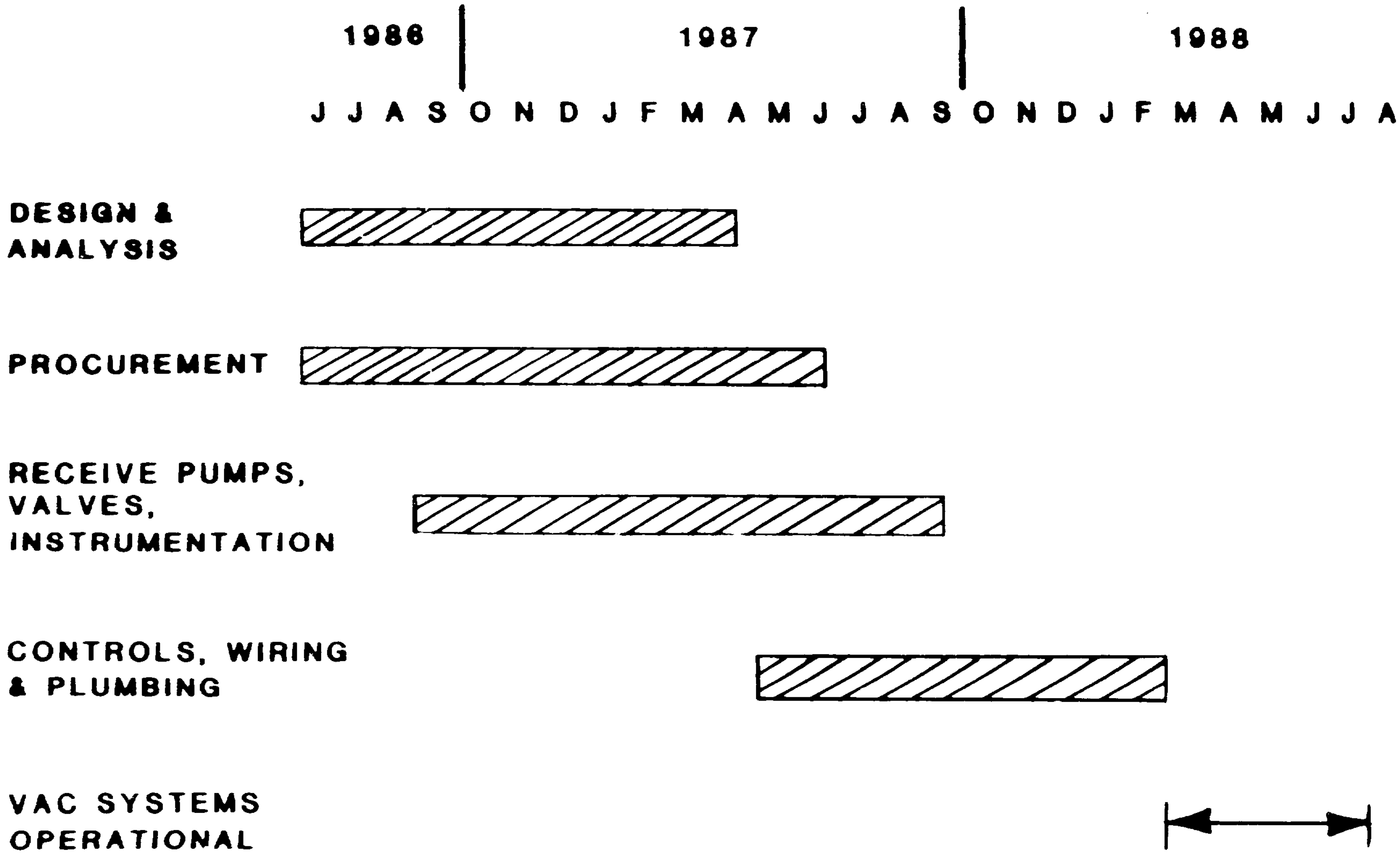
* 37	CT-8 CTI CRYOPUMPS	2	RESIDUAL GAS ANALYZERS
4	RCP321 BALZERS CRYOPUMPS	14	EXTRA RGA HEADS
* 16	LH-1000 LEYBOLD TURBOPUMPS	20	ION GAUGES
* 15	D30A ROTARY VANE MECHANICAL PUMPS	25	TC GAUGES
	CRYOPANELS IN NEUTRALIZER	53	8-INCH GATE VALVES
* 1	LH WSU1000 BLOWER	2	10-INCH GATE VALVES
* 3	LH DK200 ROTARY PISTON	60	VALVES IN SMALLER SIZES
1	LH WSU2000 BLOWER		

* or equivalent

7. Implementation

Futher design and analysis on the maturing GTA-1 design is proceeding in parallel with pump, valve, and instrumentation procurement. The use of a single diameter pump size, and the awareness that more pumps will be needed for GTA-2 allow flexible, early procurement of the bulk of GTA-1 vacuum hardware.

Early vacuum hardware will be used on subsection test stands prior to final installation on GTA-1. All vacuum equipment will be on site in time to support section by section machine build-up.


1986
1987
1988
J J A S O N D J F M A M J J A S O N D J F M A M J J A
DESIGN & ANALYSIS
PROCUREMENT
RECEIVE PUMPS, VALVES, INSTRUMENTATION
CONTROLS, WIRING & PLUMBING
VAC SYSTEMS OPERATIONAL

PLAN

III.K. MECHANICAL ALIGNMENT

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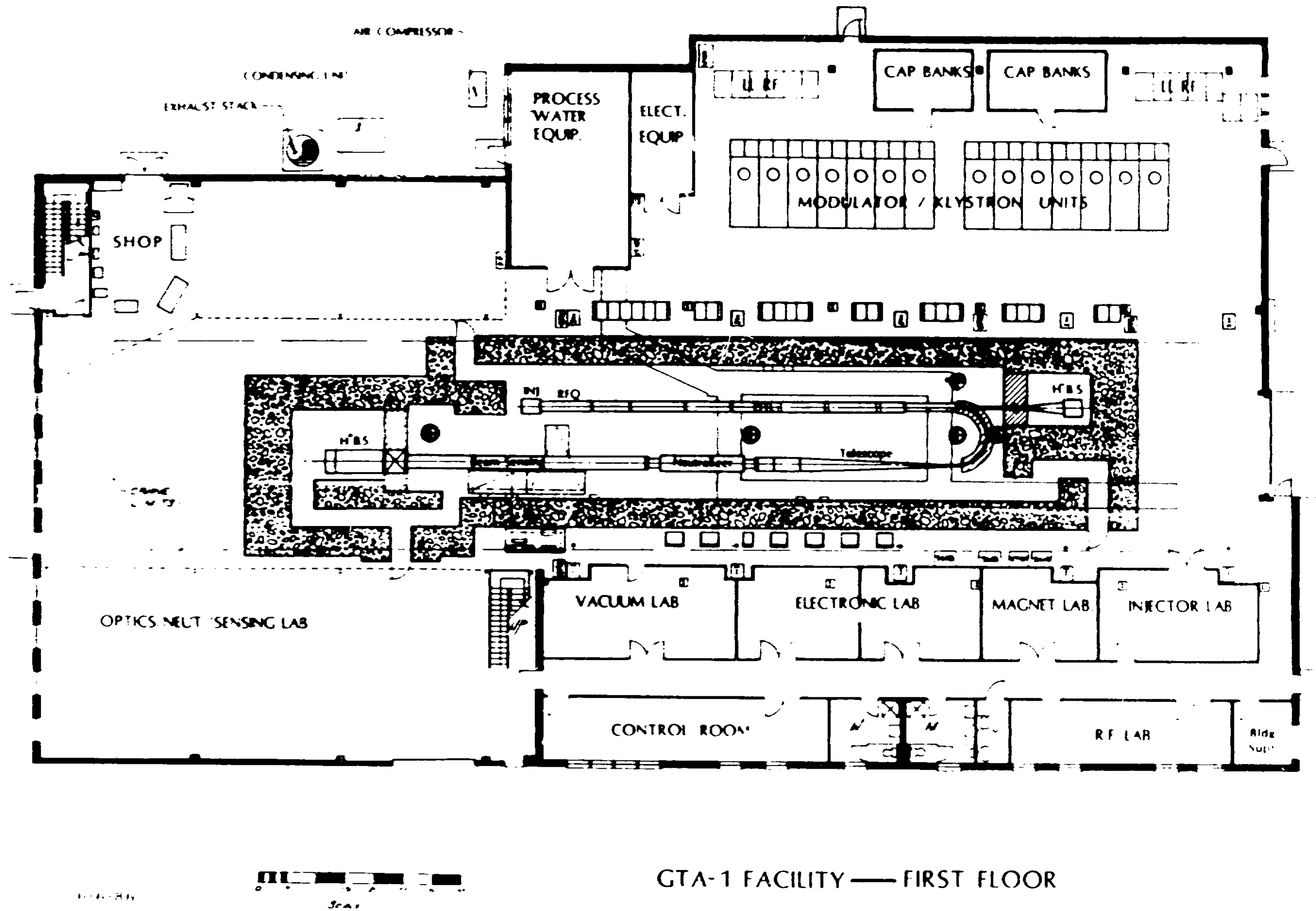
ALIGNMENT APPROACH

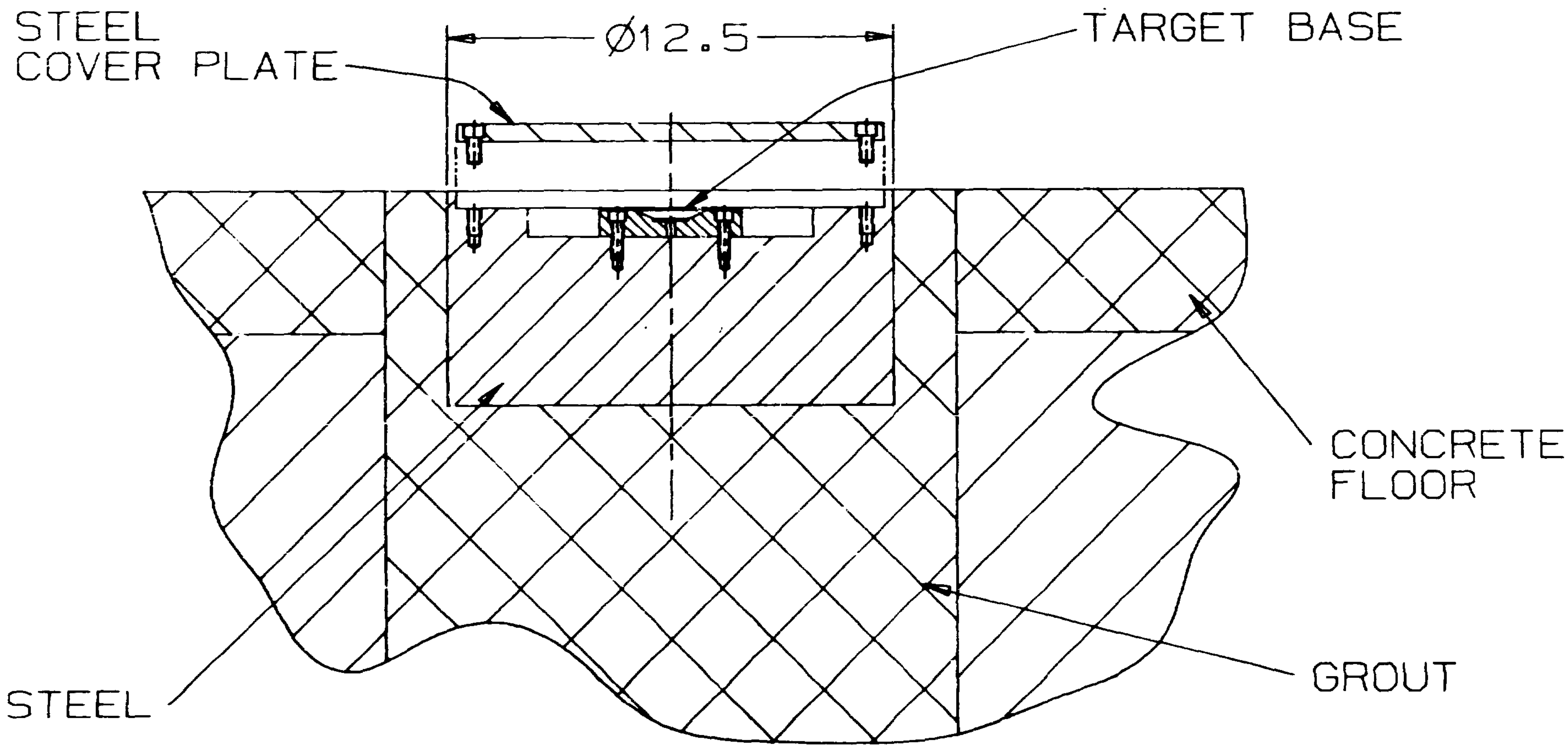
- Conventional optical tooling techniques proven in numerous accelerators and rings.
- Small team of three to four people do alignment of entire machine.
- Tooling dock not required, vendors will locate fiducials on magnets.
- Fiducial position may be measured or checked by alignment team using computer-aided theodolite.
- GTA-1 geometric control drawing (in progress) defines GTA-1 machine in relation to building and monument system.
- Fiducials need not be on axis, but offset must be known

MONUMENT SYSTEM

- Five floor monuments form reference grid in MPF-18.
- Four monuments in straight line down center of machine.
- Fifth monument defines perpendicular line to other four at center of 180° bend.
- Five monuments form horizontal reference system for all component alignment.
- Monument located at neutralizer is elevation control.
- Monuments installed as soon as building is ready.



GTA-1 FACILITY —— FIRST FLOOR



ALIGNMENT MONUMENT

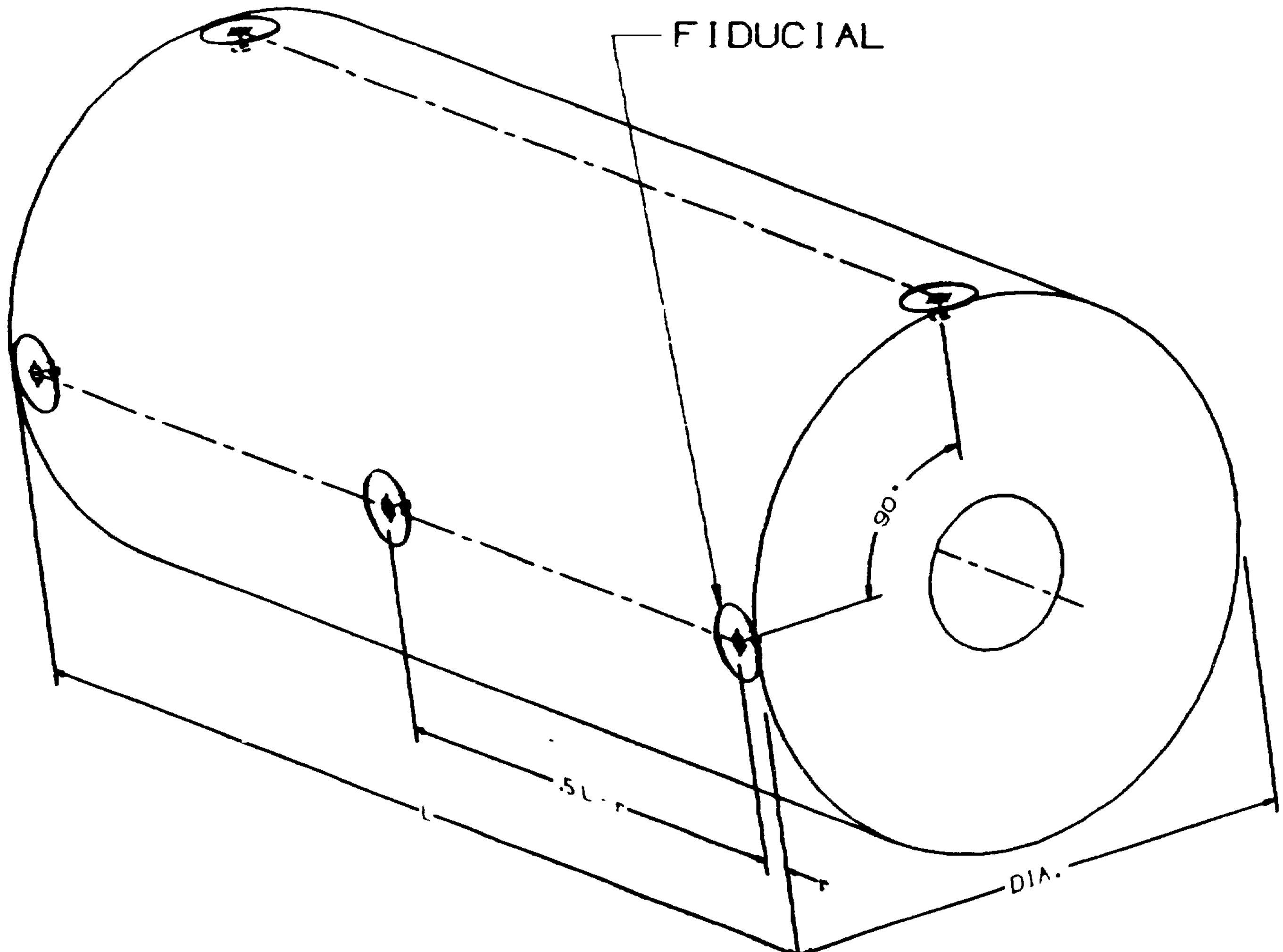
- Computer-aided Theodolite system (0.5-second resolution).
- Two optical transits (3.9-second resolution).
- Two sight levels, one automatic (3.9-second resolution).
- Various mechanical distance measuring devices.
- Three levels including an electronic differential level.
- Several unique alignment fixtures.
- Buy equipment fiscal year 1987.

REFERENCES

1. E. Hawkins "GTA Alignment Resources Required" AT-3:86-251, June 1986.

FIDUCIAL STANDARD

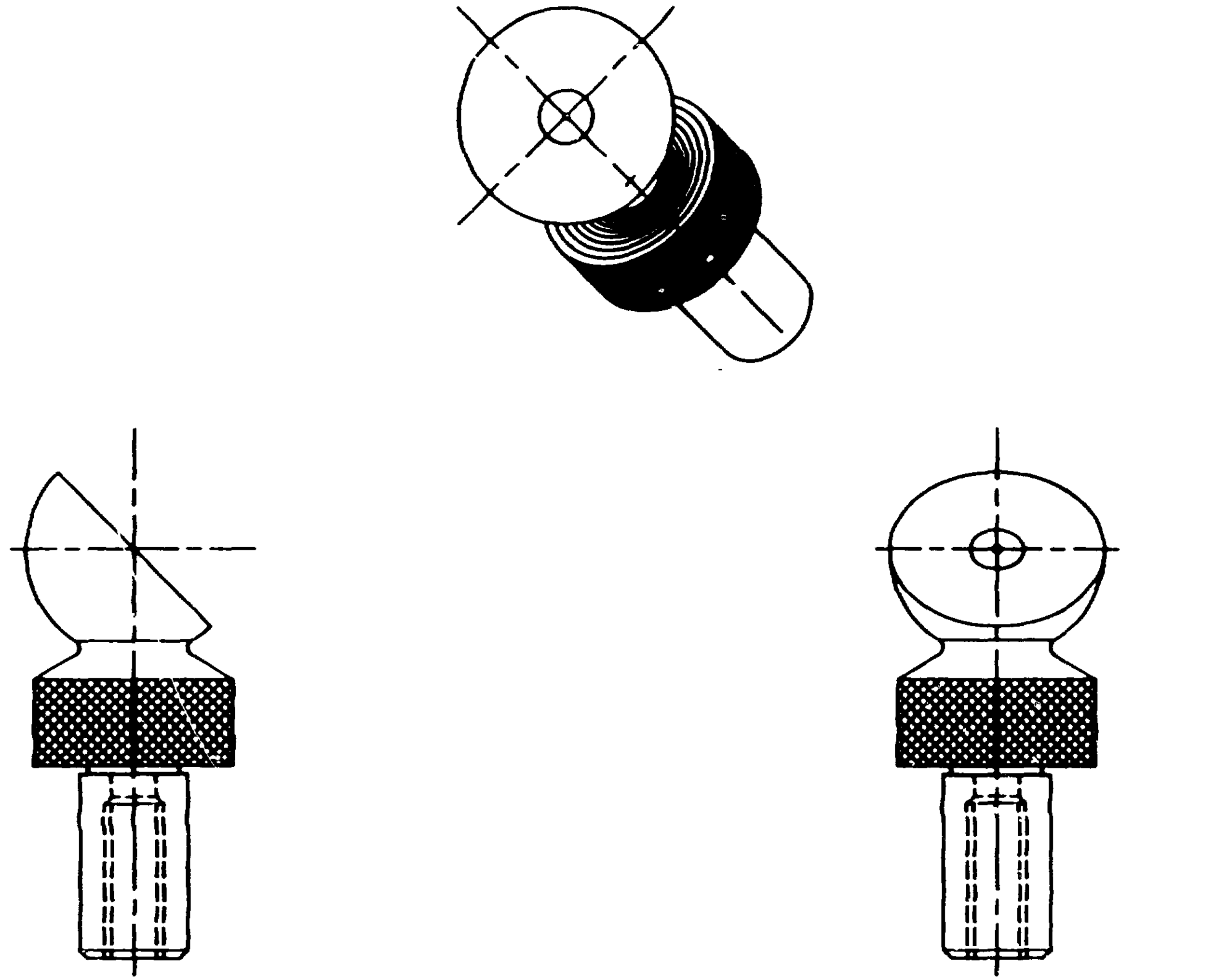
- One-square-inch flat surface with 0.2500/0.2505-in. diam. hole in center of flat perpendicular to flat.
- Minimum of two fiducials per component.
- Fiducials need not be on axis, but offset must be known.
- Alignment team can measure fiducial offset from bore, or surface datum of component.



TYPICAL COMPONENT
SHOWING FIDUCIALS

STANDARD TARGET

- Cutaway tooling ball is standard target for computer-aided Theodolite.
- Plastic plug target is standard target for optical transits and sight levels.



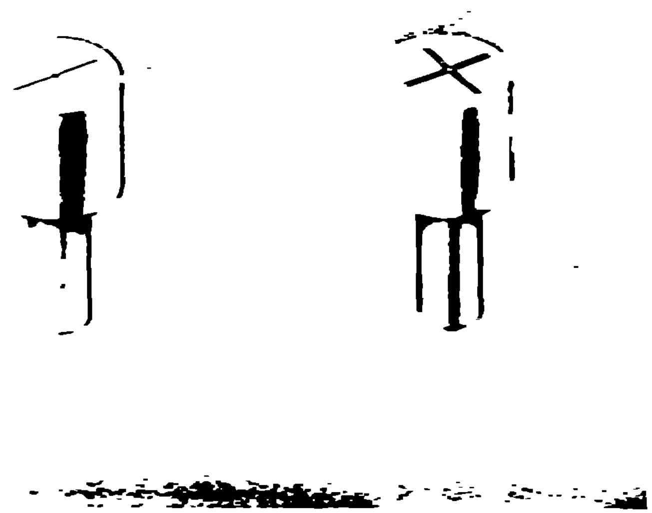
STANDARD TARGET

SMALL PLUG TARGETS ON PLASTIC

MODEL #710 SIDE VIEWING TARGET

The target consists of a multiple bi-filar pattern centered on a half section of Lucite rod. The rod is terminated in a female socket 250 inches in diameter 3/8 inch deep.

The target pattern is centered within .001 inch with respect to the centerline of the female socket. Bi-filar spacings of .010 and .020 inch on each target allow for usage at shot distances up to 25 feet. The target pattern is engraved in the half section of the rod and black filled for visibility.



MODEL #706 SIDE VIEWING TARGET

The target consists of a multiple bi-filar pattern centered on a half section of Lucite rod. The rod terminates in a machined plug. The targets are available with plug sizes of .136, .159, .201, .250, .254, .272, .312, .375, and .437 of cn inch in diameter.

The target pattern is centered within .002 inch with respect to the centerline of the plug. Bi-filar spacings of .010 and .020 inch on each target allow usage at shot distances up to 25 feet. The pattern is engraved in the half section of the rod and black filled for visibility.

ALIGNMENT TOLERANCES

- Defined for all components on GTA-1 alignment parameters drawing 112Y-269502-D1.
- Alignment tolerances specified by system managers.
- Tolerance specified determines method of alignment.

GTA-1 COMPONENT ALIGNMENT PARAMETERS

SYSTEM / SUBSYSTEM / DEVICE	DEVICE CODE	ALIGNMENT ACCURACY REQUIRED						DATE	COMMENTS/ ACTION ITEMS
		X (INCH) HORIZ. ⊥ Z	Y (INCH) VERT. ⊥ Z	Z (INCH) ALONG BEAM	PITCH ABOUT X AXIS	YAW ABOUT Y AXIS	ROLL ABOUT Z AXIS		
									SEE GTA-1-1400-1-C
ACCELERATOR									
INJECTOR		—	—	—	±2mr	±2mr	±17mr		BOLTS RIGIDLY TO RFQ
RFQ *		±.002	±.002	±.004	±.25mr	±.25mr	—		
BUNCHER *		±.002	±.002	±.004					
DTL (RG + 50 MEV) *		±.002	±.002	±.004	±.25mr	±.25mr	±.25mr		Z STACK UP TOLERANCE .010 OVER ANY 120 INCREMENT
DRIFT TUBES *		±.002	±.002	±.004	±1mr	±1mr	—		
BEAM STOP (H^-)		±.25	±.25	±.25	—	—	—		* COMPONENT TO COMPONENT ALIGNMENT, ALL RIGIDLY TIED TOGETHER. SPACERS MAY BE MACHINED AFTER TRIAL ASSEMBLY.
OPTICS									
MATCHING SECTION									
WIRE SCANNER		±.06	±.06	±.12	—	—	±2 DEG.		
POSITION MONITOR		±.04	±.04	±.12	—	—	±2 DEG.		
QUADRUPOLE (TRIPLET)									
CURRENT MONITOR		±.06	±.06	±.12	—	—	—		
STEERING MAGNET		±.06	±.06	±.12	—	—	±2 DEG.		
SLIT									
QUADRUPOLE (DOUBLET)									
180° BEND									
DIPOLE		±.020	±.020	±.020	±1 DEG.	±1 DEG.	±1 DEG.		
QUADRUPOLE (FOCUSING)		±.010	±.010	±.020	±2 DEG.	±2 DEG.	±1 DEG.		
QUADRUPOLE (DEFOCUSING)		±.010	±.010	±.020	±2 DEG.	±2 DEG.	±1 DEG.		
TELESCOPE									
POSITION MONITOR		±.04	±.04	±.12	—	—	±2 DEG.		
SLIT									
WIRE SCANNER		±.06	±.06	±.12	—	—	±2 DEG.		
QUADRUPOLE (DOUBLET)									
POSITION MONITOR		±.04	±.04	±.12	—	—	±2 DEG.		
STEERING MAGNET		±.06	±.06	±.12	—	—	±2 DEG.		
CURRENT MONITOR		±.06	±.06	±.12	—	—	—		
PROFILE MONITOR									
QUADRUPOLE (TRIPLET)									
STEERING COIL									
NEUTRALIZER									
BEAM SENSING									

III.L BEAM DIAGNOSTICS: RECOMMENDATIONS AND ISSUES

Beam diagnostics should permit the operator and experimenter to detect beam wander and emittance growth (transverse and longitudinal) after each major component.

Significant work is required to develop and qualify on line diagnostics

Off line diagnostics to measure emittance and related parameters require major development.

Beam diagnostics and controls must be closely linked.

Accelerator physicists and engineers should specify their requirements for beam commissioning and insist that they are incorporated into the control and diagnostic designs.

ON LINE DIAGNOSTICS:

Beam Position Monitors	Microstrip lines in accelerator; striplines in HEBT
Profile Monitors	Non-interceptive monitors (microstrip lines and gas ionization)
Current Monitors	Toroids in LEBT and HEBT; microstrip lines in and between DTL tanks
Beam Energy Measurment	Time-of-flight between DTL tanks and around the 180o bend
Beam Spill	Radiation monitors and current measurements
RF Phase	Microstrip lines for bunch synchronous phase and tuneup
Neutral Beam Sensing	Mechanical (wire, pinholes) or laser resonance (LRF, ICA)

OFF LINE DIAGNOSTICS:

Source and LEBT	Electric sweep emittance scanner; Faraday cups
RFQ	Spectrometer after
DTLs	Spectrometers: 6 MeV<W<50 MeV
HEBT	Wire scanners; harps; LINDA
Telescope Evaluation	Pinhole imaging camera
Scoring System	Partially interceptive pinhole or shadow camera

BEAMLINE DIAGNOSTIC LIST

TYPE	ACCELERATOR	HEBT
BPM (Microstrip & Strip)	46	15
Profile (Wire Scanners & Harps)	2nd Moment BPM	12
Fluorescent Screen Monitors	0	3-12
Current Toroids	7	2
Momentum	Sync Phase BPM	2
Beam Loss	7	8
Emittance	LINDA	Pinhole Imaging
Beam Sensing	0	1
Beam Scoring	0	1
Beam Stop	Temporary	2
Total	61	44+

LOCATION AND FUNCTION OF MICRO-STRIPLINE BEAM POSITION MONITORS

			First Priority						Later Priority		
BPM	TANK	Drft Tb	x	y	Energy	Syn Phs	I-avg	I-pk	x-wdth	y-wdth	Ø-wdth
1		ITS-0	yes	yes			yes				
2		ITS-1	yes	yes	yes	yes	yes	yes			
3	DTL-2	30	yes	yes	yes	yes	yes	yes			
4	DTL-2	31	yes	yes			yes				
5	DTL-2	32	yes	yes			yes				
6	DTL-2	36	yes	yes			yes				
7	DTL-2	40	yes	yes			yes				
8	DTL-2	44	yes	yes			yes				
9	DTL-2	48	yes	yes			yes				
10	DTL-2	53	yes	yes			yes				
11	DTL-2	54	yes	yes			yes				
12		ITS-2	yes	yes	yes	yes	yes	yes			
13	DTL-3	55	yes	yes	yes	yes	yes	yes			
14	DTL-3	56	yes	yes			yes				
15	DTL-3	57	yes	yes			yes				
16	DTL-3	61	yes	yes			yes				
17	DTL-3	65	yes	yes			yes				
18	DTL-3	68	yes	yes			yes				
19	DTL-3	69	yes	yes			yes				
20		ITS-3	yes	yes	yes	yes	yes	yes			
21	DTL-4	70	yes	yes	yes	yes	yes	yes			
22	DTL-4	71	yes	yes			yes				
23	DTL-4	72	yes	yes			yes				
24	DTL-4	75	yes	yes			yes				
25	DTL-4	78	yes	yes			yes				

LOCATION AND FUNCTION OF MICRO-STRIPLINE BEAM POSITION MONITORS

26	DTL-4	81	yes	yes			yes	
27	DTL-4	82	yes	yes			yes	
28		ITS-4	yes	yes	yes	yes	yes	yes
29	DTL-5	83	yes	yes	yes	yes	yes	yes
30	DTL-5	84	yes	yes			yes	
31	DTL-5	85	yes	yes			yes	
32	DTL-5	88	yes	yes			yes	
33	DTL-5	92	yes	yes			yes	
34	DTL-5	93	yes	yes			yes	
35		ITS-5	yes	yes	yes	yes	yes	yes
36	DTL-6	94	yes	yes	yes	yes	yes	yes
37	DTL-6	95	yes	yes			yes	
38	DTL-6	96	yes	yes			yes	
39	DTL-6	100	yes	yes			yes	
40	DTL-6	103	yes	yes			yes	
41	DTL-6	104	yes	yes			yes	
42		ITS-6	yes	yes	yes	yes	yes	yes
43	DTL-7	105	yes	yes	yes	yes	yes	yes
44	DTL-7	106	yes	yes			yes	
45	DTL-7	108	yes	yes			yes	
46	DTL-7	109	yes	yes			yes	
47		ITS-7	yes	yes	yes	yes	yes	yes

BEAM POSITION MONITORS

Type: Non-interceptive

Number: 4 in matching section
1 in HEBT to H^- beam dump
7 in 180 deg bend (inside quads)
1 before telescope eyepiece
1 at telescope objective (large diameter)

Sensors: Stripline, 1/4 wavelength
x and y in same detector

Processing: Frequency downshift to 5 MHz
Amplitude-to-phase conversion
Simultaneous digitization
Resolution 0.1 mm
Beam stabilization

Current Monitors

Type: Toroid (beam current transformer)

Number:
1 in matching section
1 in HEBT to beam dump
1 after bend

Processing:
Gated integrator for average current
Slow A/D conversion for avg. current
Fast A/D conversion for pulse shape
Built-in calibration winding
0.1 % accuracy

Momentum Detector

A. Time-of-flight

- 2 wideband pickups about 5 m apart
- Phase comparison at 425 MHz
- 1 deg phase yields dp/p of 1.6×10^{-4} (14 keV)
- absolute energy measurement to ~ 10^{-3}
- sensitive to longitudinal pulse shape
- track-and-hold ; digitization
- slow feedback to linac rf phase via computer
- fast feedback possible (10 kHz)

B. Beam Position at 90 degrees

- high dispersion point (1 cm / %)
- BPM sensitivity of 0.1 mm yields dp/p of 10^{-4}
- Mixes momentum and steering effects
- No absolute calibration

Profile Monitors

A. Non-Interceptive

1. Residual Gas Ionization

- Resolution about 0.5 mm
- Suited for high-intensity, expanded beam
- Prototype under construction

2. Quadrupole moments from BPMs

- Reconstruction from >6 measurements
- Under investigation for linac

Profile Monitors (Continued)

B. **Partially-Interceptive**

1. **Wire scanners**

- High resolution
- Suited for small-diameter beam
- Secondary emission vs. collection
- Number:

  2 in matching section
  2 in HEBT beam dump line
  4 in 180 deg bend
  1 before telescope eyepiece
  1 in telescope

2. **HARPS**

- Resolution about 0.5 mm (can increment)
- More destructive (OK after telescope)
- Fast tune-up
- 10 pC per wire sensitivity
- Number: 2 after telescope objective

Profile Monitors (Continued)

C. **Totally-Interceptive**

1. **Phosphors**

- Chromium-doped aluminum oxide
- Visual indication
- Video digitization
- x - y correlations
- Number:

  include with WS where feasible
  2 after telescope (with Harps)
  1 in pinhole experiment

2. **Segmented Faraday Cup**

- Low intensity beam (Argonne Exp.)
- about 1 mm resolution

Loss Monitors

Type: Under investigation
Possibilities:
- Coated photomultiplier
- PIN diode
- Scintillator
- Gas Ionization chamber

Number: about 8

Processing: integrator, amplifier
hardware trip point for fast protect

Emittance Measurement

A. **Laser Neutralization (LINDA)**

- About 4 meter drift
- Charged beam deflection by electromagnet
- Phosphor screen - video digitization
- Number:

  1 after linac in HEBT

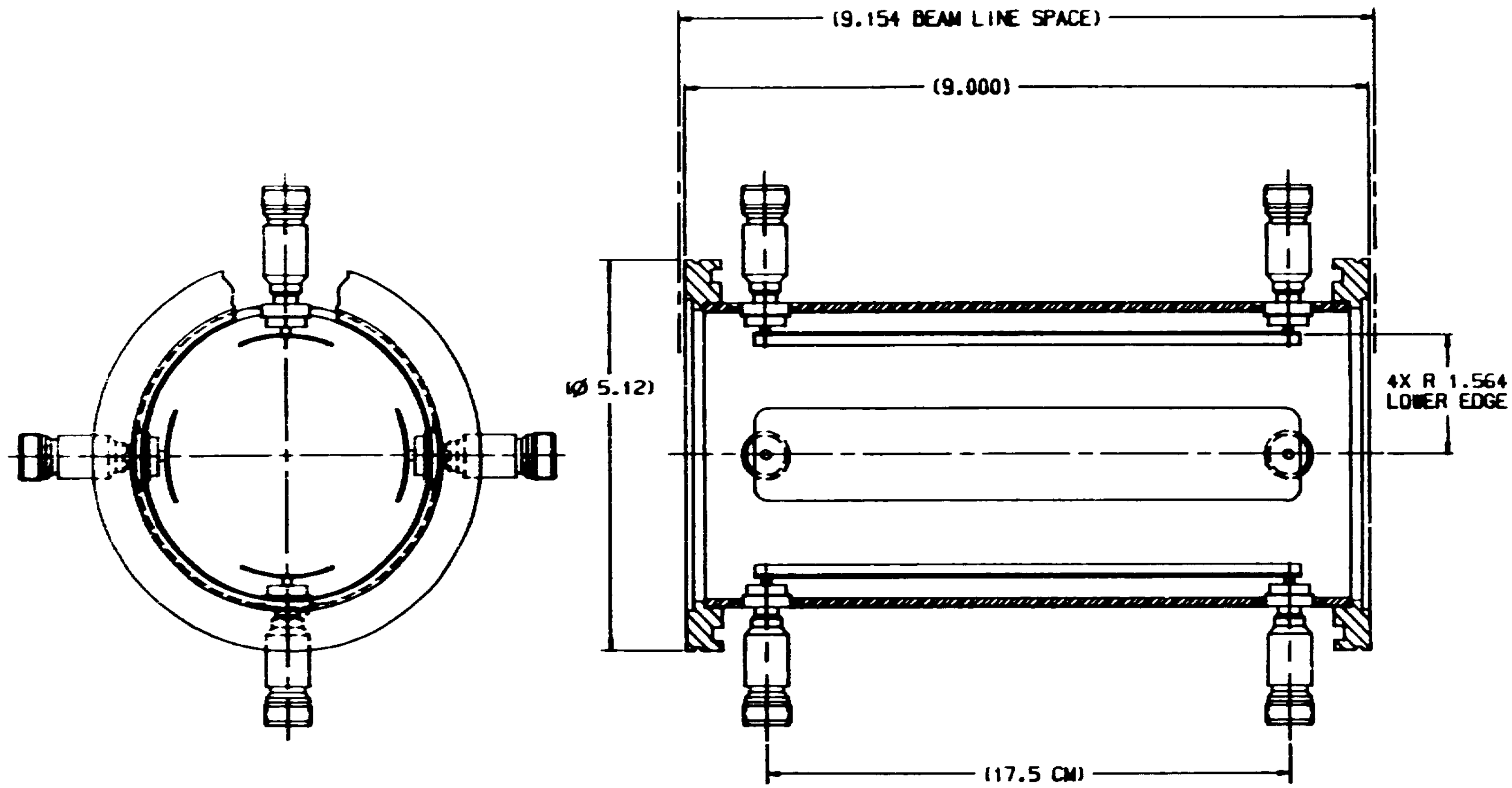
  perhaps 1 after 180 degree bend

B. **Three Wire Scanners in Drift Section**

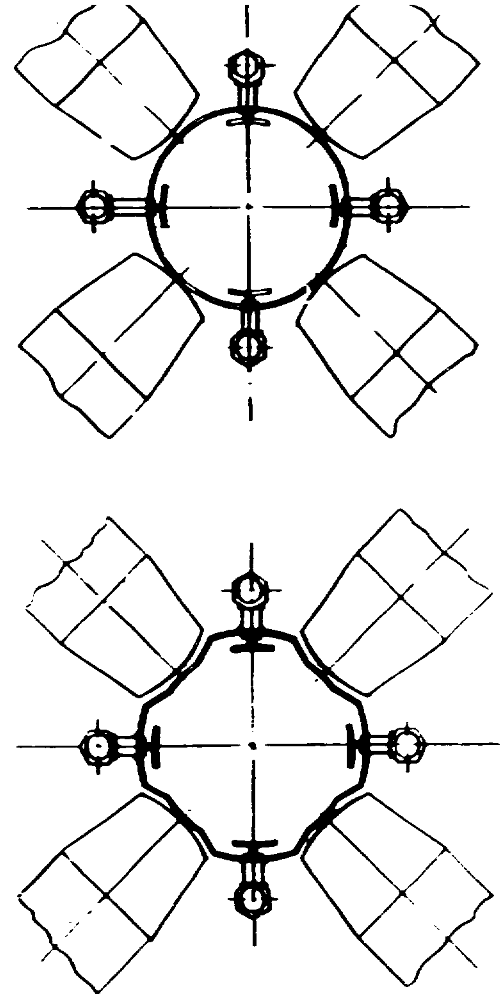
- Electromagnetic quads in matching section
- Tailor beam to optimize measurement
- Not an on-line measurement

C. **Pinhole Imaging After Telescope**

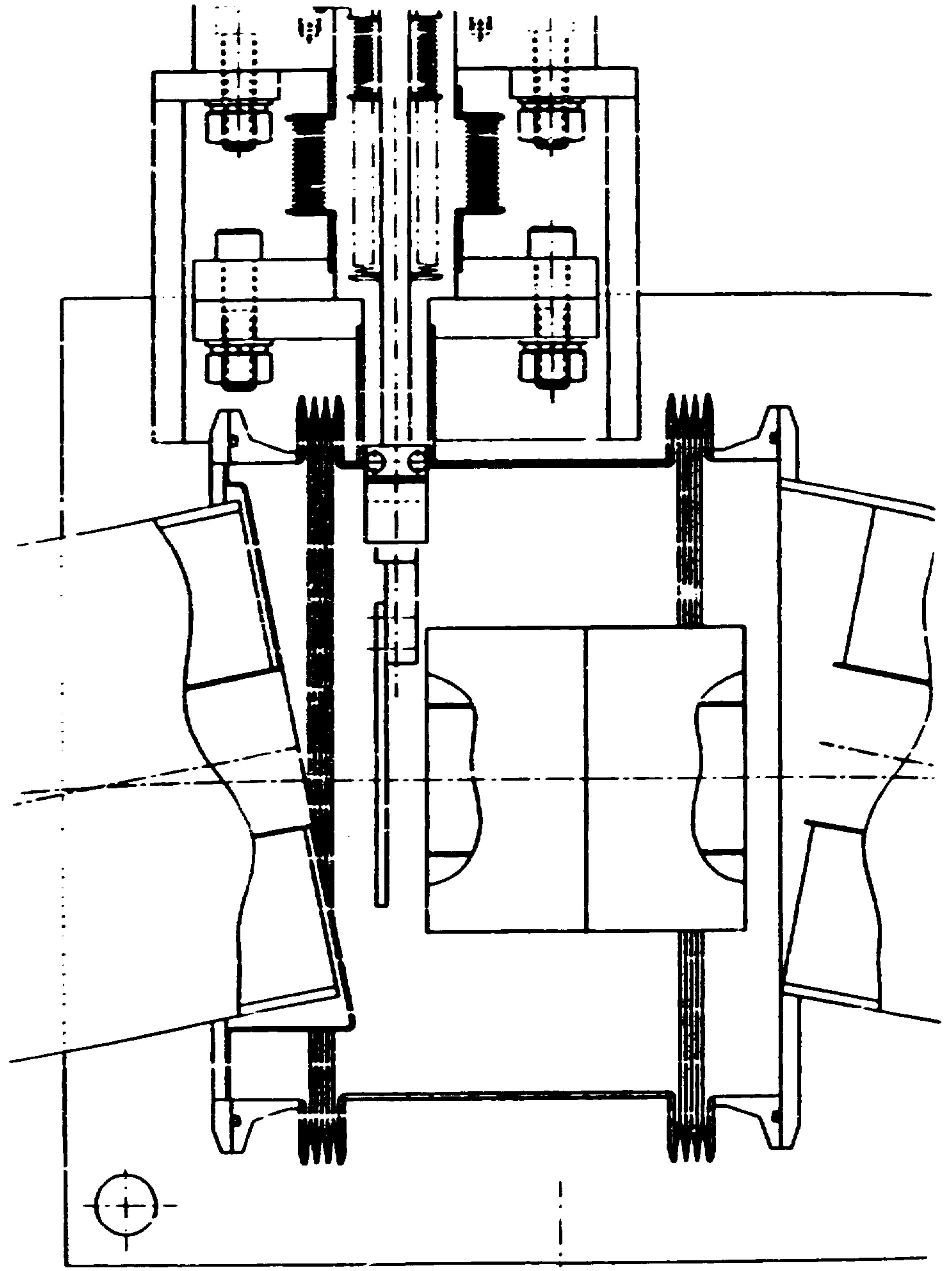
- Telescope characterization
- 10-meter drift
- Phosphor - video digitization
- Being developed by beam sensing team
- Test at Argonne - 1987



Beam Position Monitor for Argonne - Telescope Beam line

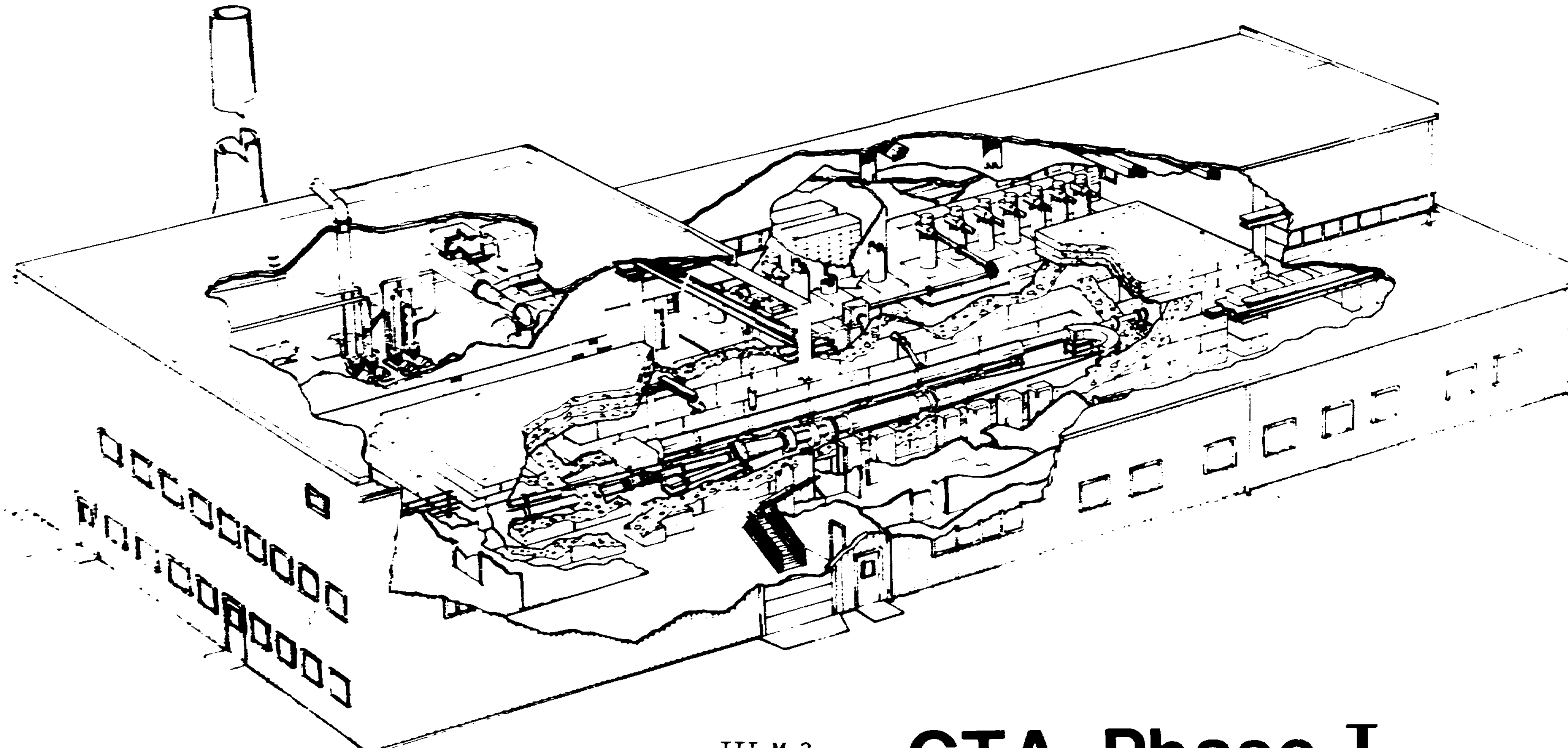


Other types of possible BPM sensors for GTA-1, shown within the poles of a hybrid, permanent magnet quadrupole



Possible configuration of wire scanner in 180° bend

III. M. GTA PHASE 1 FACILITY



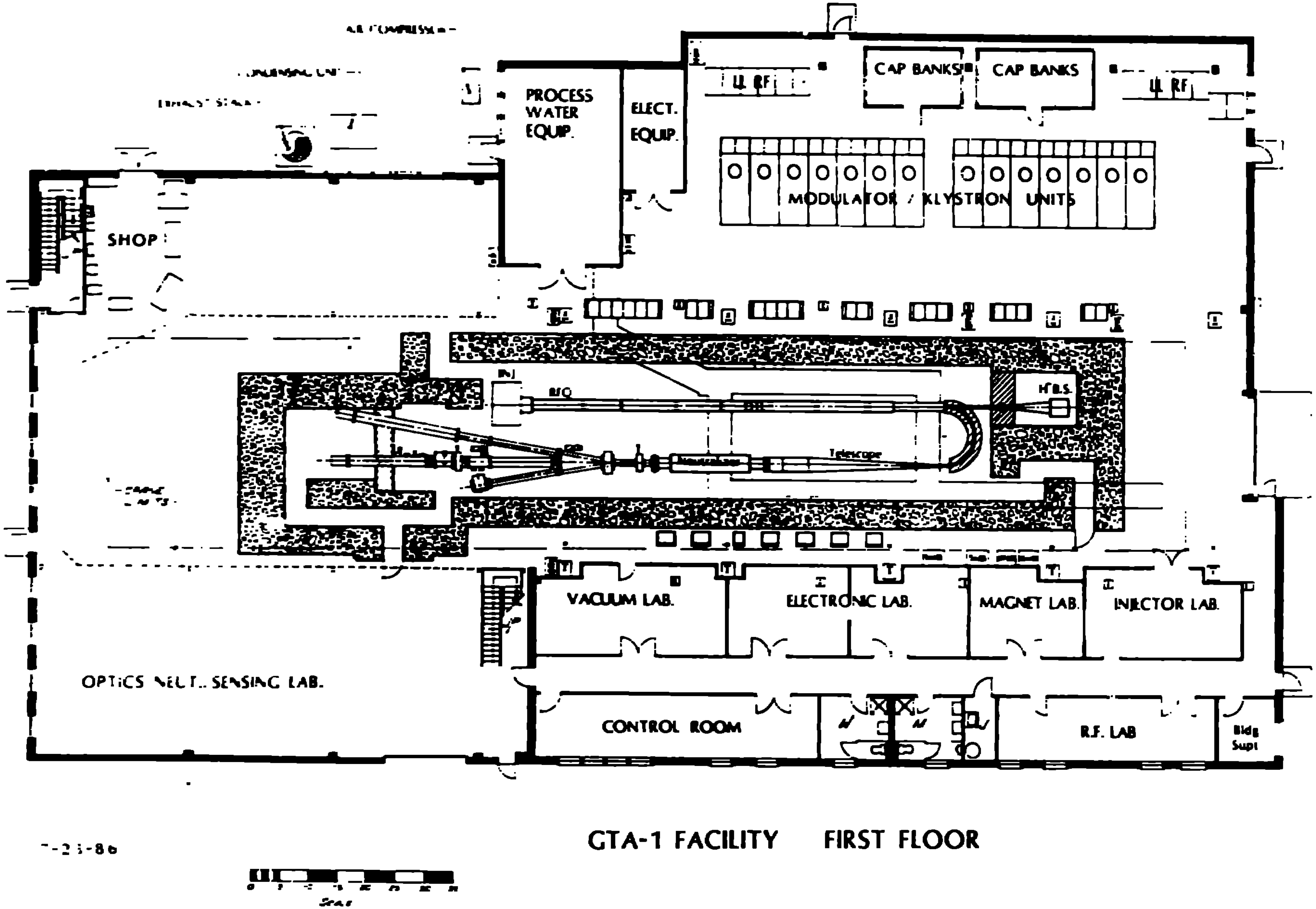
III.M-2

GTA Phase I

GTA-1 Facility

FACILITY STATUS:

- BIDS FOR RENOVATION AND ADDITION OPENED AUGUST 7, 1986
- SCHEDULED COMPLETION APRIL 1987
- MUST CONFIRM RF TRANSMISSION PATHS BY AUGUST 28, 1986
- IC&D ELECTRONIC RACK REQUIREMENTS TO BE FINALIZED BY SEPTEMBER 1986
- CONSTRUCTION HAS BEEN AUTHORIZED AND FUNDED

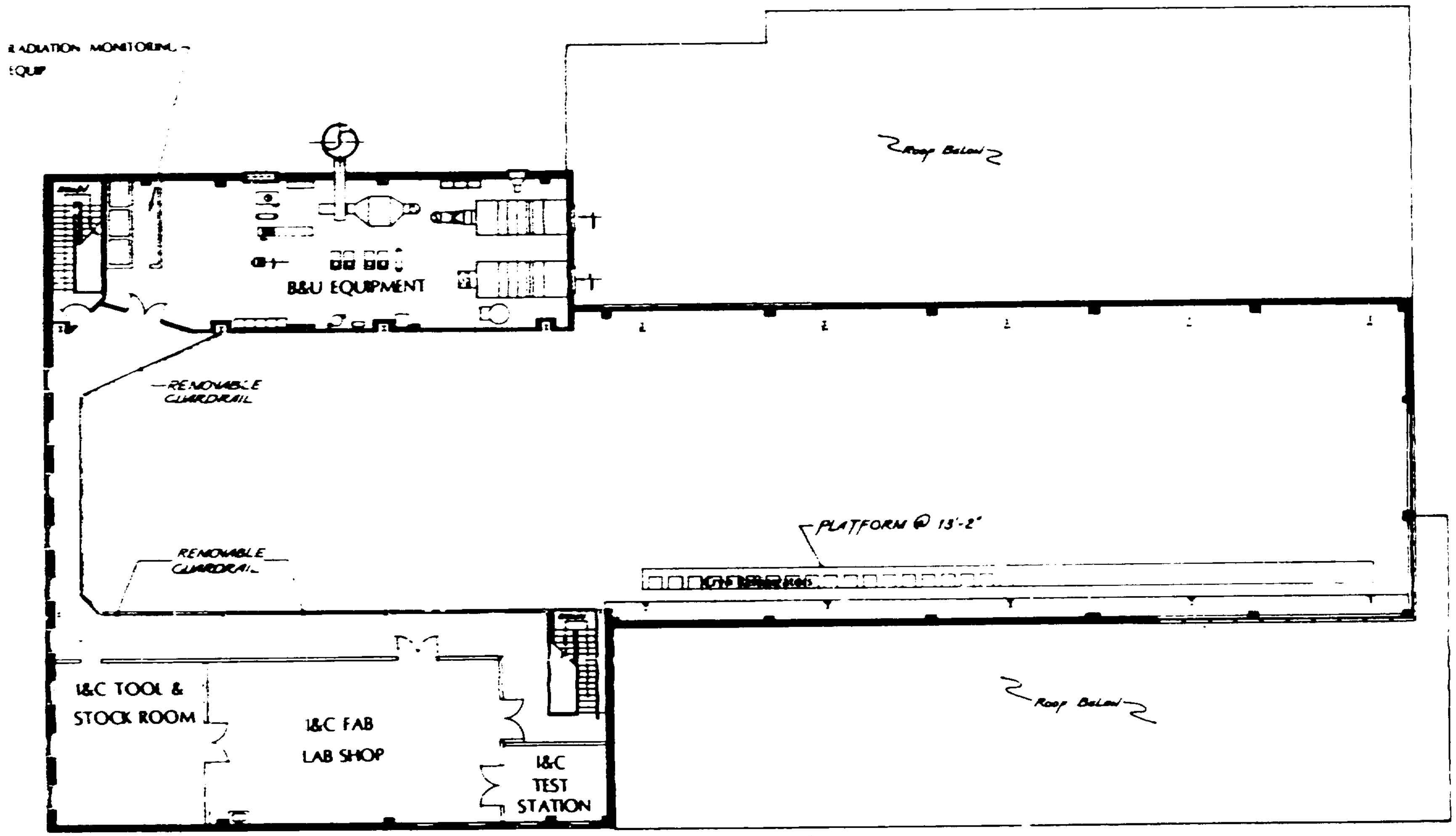


GTA-1 FACILITY FIRST FLOOR

GTA-1 Facility

FACILITY LAYOUT - FIRST FLOOR:

- ACTIVATED AIR HANDLING FOR TUNNEL
- PERSONNEL SAFETY INTERLOCK SYSTEM FOR TUNNEL
- LIMITED SPACE IMPEDES INSTALLATION, TUNEUP, MAINTENANCE AND OPERATIONS
- MECHANICAL ASSEMBLY AREA
- LARGE RF SYSTEM SPACE BUT DIFFICULT TRANSMISSION PATHS



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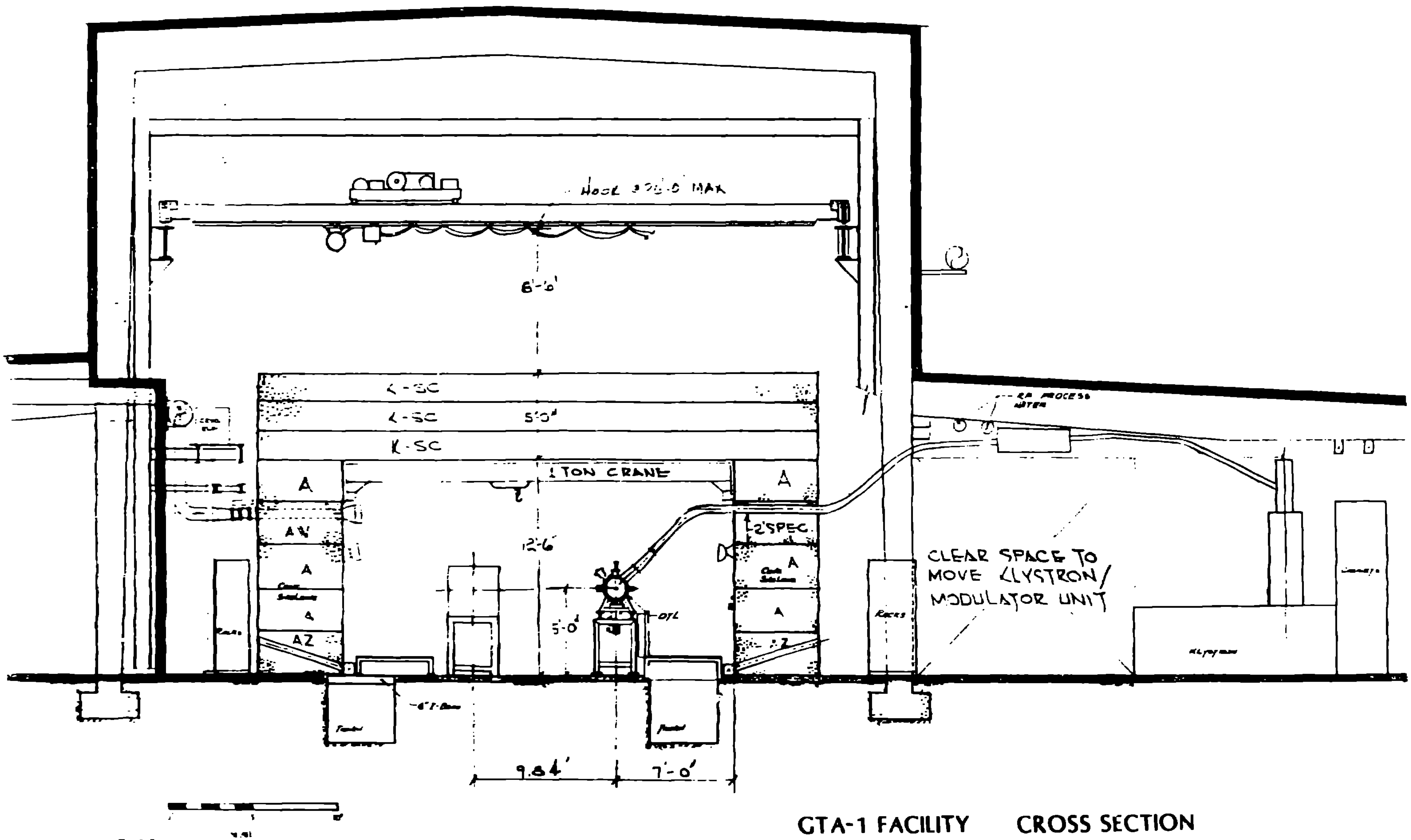
GTA-1 FACILITY —— SECOND FLOOR

FACILITY LAYOUT - SECOND FLOOR:

- BUILDING UTILITY SYSTEMS SPACE
- ELECTRONIC FABRICATION AND CHECK-OUT SPACE
- RADIATION MONITORING INSTRUMENT SPACE
- HIGH BAY TO CLEAR TUNNEL AND PROVIDE BRIDGE CRANE WORKING SPACE



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GTA-1 FACILITY CROSS SECTION

FACILITY LAYOUT - CROSS SECTION

- SHIELD BLOCK THICKNESS DEFINES ALL OTHER SPACE
- RF TRANSMISSION SYSTEM IS SPACE LIMITED
- SUB-SYSTEMS ARE SPACE LIMITED
- RADIATION STREAMING PATHS MINIMIZED
- SHIELD BLOCK HANDLING SPACE OVER TUNNEL IS MINIMAL

GTA-1 Facility

REQUIREMENTS:

- PHYSICS FOOTPRINT OF THE GTA-1 SYSTEM
- SUB-SYSTEM SIZES AND REQUIREMENTS
- RADIATION BULK SHIELDING SIZES
- EXPERIENCED HIGH TECHNOLOGY ARCHITECT ENGINEER

GTA-1 Facility

CRITERIA:

- MODIFY BUILDING MPF-16 TO CONTAIN THE GTA-1 SYSTEM
- MODIFY THE 14 MW SUB-STATION AS NECESSARY
- MODIFY THE 4.25 MW COOLING TOWER AND PUMPING SYSTEM
- PROVIDE AS MUCH LABORATORY, ASSEMBLY, MAINTENANCE AND SHOP SPACE AS POSSIBLE
- DESIGN TO CONFORM TO ALL APPLICABLE CODES AND REGULATIONS

III.N GTA Beam Transport Overview

The GTA accelerator can be divided into several distinct beam dynamics subsystems which correspond very much to the subdivisions of the accelerator hardware already described. These are namely the Ion-source, LEBT (low energy beam transport), the RFQ (radio frequency quadrupole), the DTL (drift tube linac) structures and the output optics.

There are several beam dynamics concerns common to all of the sub-systems as well as concerns special to each particular sub-system. The objective of this section is to identify the beam dynamics topics of general concern, the tools currently being used in the designs including their strengths and deficiencies and the areas of interface between the subsystems. An attempt will also be made to identify the areas where the physics understanding has to be advanced if the technology is to advance to the kinds of beam quality required beyond that of the GTA-1 project.

Ion Source

Design Objectives

Current >135 mA H^- extracted
Energy 100 keV

Tools available for Ion-source design:

Experience	ATS and BEAR Ion-sources operational.
KOBRA	multi-particle ray-tracing code plus iterative Poisson solution using 3-D mesh, CW beams.
ISIS	multi-particle ray-tracing code, particle-in-cell, 2-D (r-z) electric and magnetic fields, 3-D particle coordinates and velocities, pulsed beams.

Factors influencing achievement of objectives:

Beam current instabilities.
Day to day reproducibility and reliability.
Pulsed extraction voltage cleans up beam for acceleration.
Vacuum pressure oscillations couple to beam oscillations.

Long term concerns and objectives:

At longer pulse lengths plasma instabilities increase.
Need to understand plasma dynamics correlating theory and experiment.

LEBT

Design Objectives

>120 mA H- to RFQ matched
Emittance 0.17 π mm mrad rms normalized
Transmission 90%

Tools in use for LEBT design:

TRACE3D linear matrix representation, linear space charge, permanent magnet quadrupole representation, optimization.

Factors influencing achievement of objectives:

Beam optics sensitive to neutralization.
Percent neutralization is unknown.
Experimental methods of measuring neutralization are being developed on ATS.
Movable permanent quadrupoles may not be the ideal variables to allow proper matching into the RFQ.
A large fraction of the emittance growth occurs in the accelerating column .

Long term concerns and objectives:

Design optimization of the accelerating column to minimize aberrations.
Examination of alternative focusing methods, variable permanent quadrupoles, electrostatic quads, solenoidal channels.

RFQ

Design Objectives

Current >106 mA
Energy 2.07 MeV
Emittance < 0.2 π mm mrad rms normalized
Transmission 88%

Tools in use for RFQ design:

CURLI	determines operating current limits and defines parameters of the gentle buncher.
RFQUIK	uses CURLI data to optimize length and minimize RF power.
PARMTEQ	detailed multi-particle ray-tracing code using ideal potential functions, 2 1/2-D (r-z) space charge.
PARI, VANES	generate detailed vane geometry based on beam dynamics design.

Factors influencing achievement of objectives:

Beam may be partially neutralized at entrance to RFQ.
Some disagreement between different simulations and experiment.

Long term concerns and objectives:

Understanding factors contributing to emittance growth in the presence of space-charge.
Emittance growth will become more dominant at lower frequencies, higher current, lower velocity particles.
Improvement in modelling the RFQ end regions.
Complete 3-D space-charge calculation in design codes.

DTL

Design Objectives

Current >100 mA
Energy 50 MeV nominal
Emittance 0.2 π mm mrad rms normalized
Transmission 99%

Tools in use for DTL design:

SUPERFISH cavity design code, assures Kilpatrick surface field limit not exceeded.

PARMILA simulation code, uses SUPERFISH input, give cell dimensions, 2 ½ D (r-z) space charge assumes cylindrically symmetric beam.

Factors influencing achievement of objectives:

Drift tube misalignment introduces coherent oscillations.
Compensating steering difficult to include at low energy.
Drift tube quadrupole harmonics add emittance growth.
Split quadrupoles requires matching tank to tank contributing to emittance growth.
Beam current oscillations may couple to energy oscillations.

Long term concerns and objectives:

Complete 3-D space-charge calculation in design codes.
Calculation of beam halo and beam loss.

Output Optics

Design Objectives

180° Bend doubly achromatic including space-charge, approximately 1:1 imaging.

Telescope minimizes chromatic and geometric aberrations.

Steerer minimizes chromatic and field quality aberrations.

Tools in use for the 180° bend design:

TRACE3D	linear matrix representation, linear space charge, permanent magnet quadrupole representation, optimization.
PATH	linear matrix representation, non-linear space charge, no optimization.
SCHAR	ray-tracing, non-linear space charge, no optimization.

Tools in use for the telescope design:

TRACE3D	linear matrix representation, linear space charge, permanent magnet quadrupole representation, optimization.
MARYLIE	Lie algebra, no space charge, optimization, limited fringe field representation.
MOTER	high order ray-tracing, no space charge, optimization, permanent magnet field representation.

Output Optics (con't)

Factors influencing achievement of objectives:

- Sensitivity of solution to beam current and energy.
- Sensitivity of optics to misalignments and jitter.
- Ability to compensate telescope aberrations.
- Non-linear space-charge effects in the bend, non-linear resonances.
- Field quality in steerer extremely tight.
- Chromatic requirements for steering very tight.

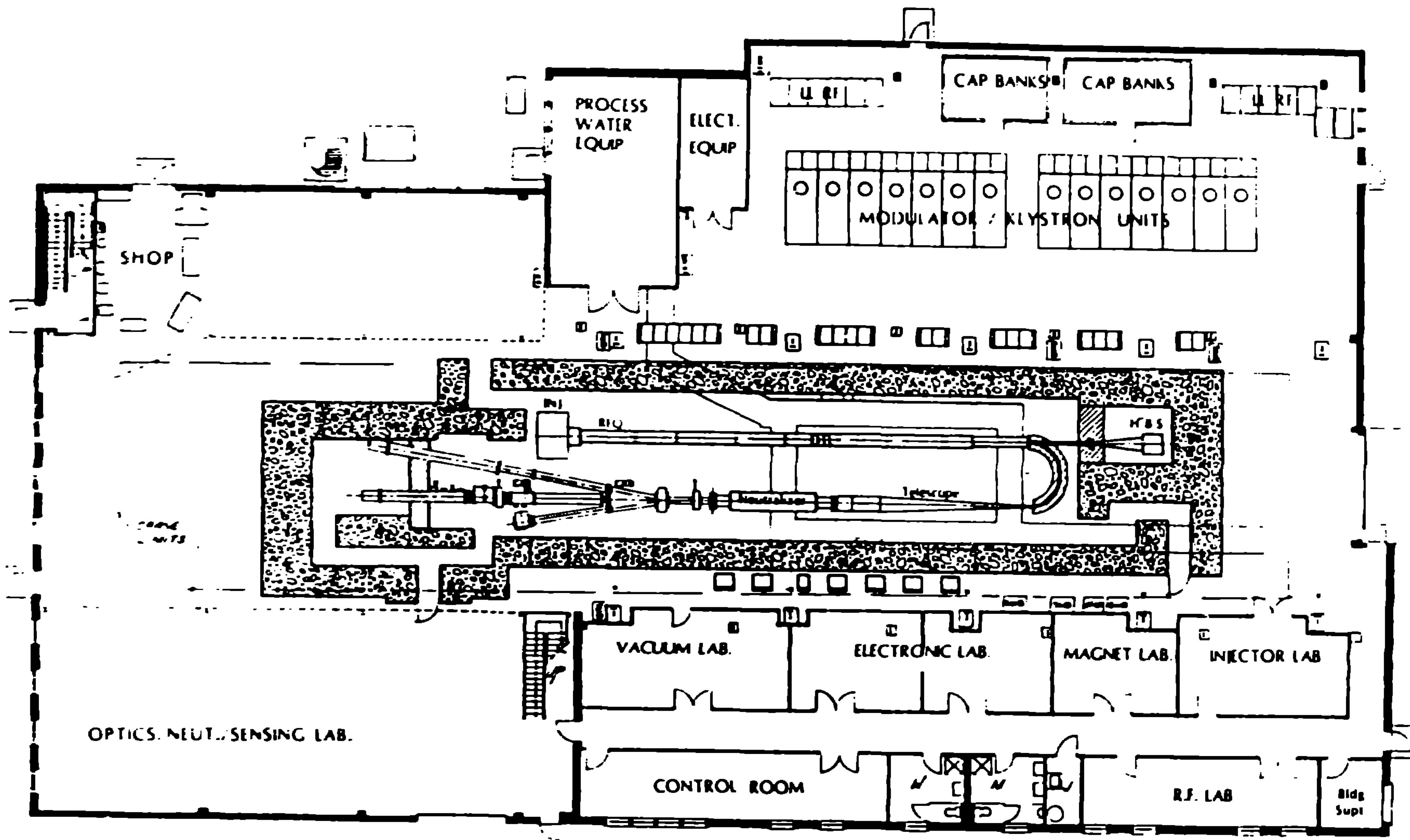
Long term concerns and objectives:

- Design code to include non-linear space-charge and high order aberrations.
- Steering at large angles needs investigation of alternative systems, combined steering and focusing, tunable multipole elements.

III.O Radiation Safety

OBJECTIVE:

- GENERATE SOURCE TERMS AND FULLY DESCRIBE THE RADIATION EXPECTED FROM GTA-1
- DEFINE SHIELDING MATERIALS AND CONFIGURATIONS
- DESIGN TO MEET DOE ORDER 5480.1 REVISION AND LABORATORY RADIATION PROTECTION REQUIREMENTS


PROCESS WATER EQUIP
ELECT. EQUIP
CAP BANKS
CAP BANKS
MODULATOR / KLYSTRON UNITS
SHOP
OPTICS. NEUT./SENSING LAB.
VACUUM LAB.
ELECTRONIC LAB.
MAGNET LAB.
INJECTOR LAB
CONTROL ROOM
R.F. LAB
Bldg Supt

REQUIREMENTS:

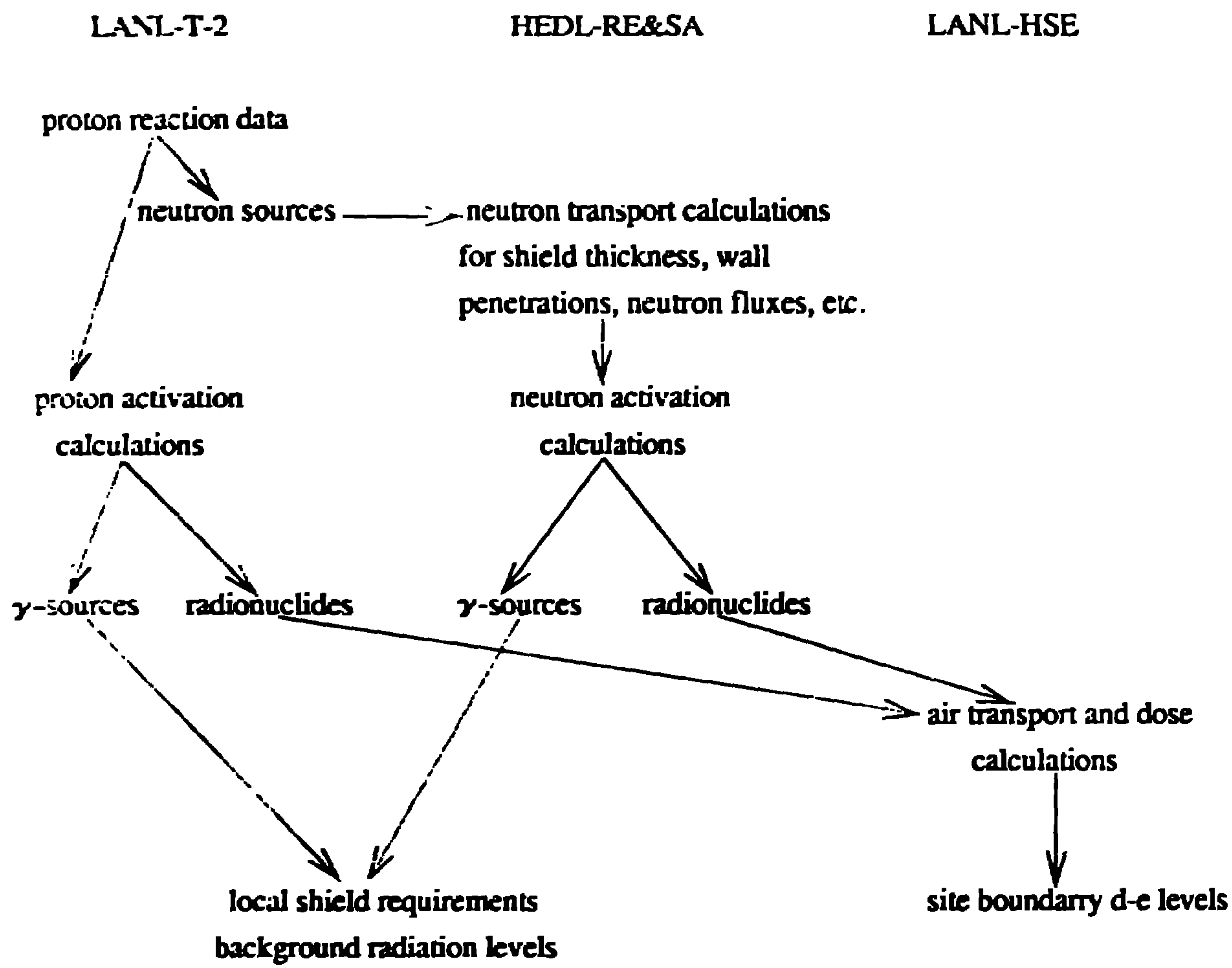
- SPECIFY BULK SHIELDING MATERIALS AND THICKNESS
- PROVIDE AIR ACTIVATION DATA AND THE LARGEST OFFSITE DOSE RESULTING FROM ROUTINE RELEASES AND ACCIDENTAL RELEASES
- PROVIDE RADIATION STREAMING DATA FOR LABYRINTHS AND OTHER SHIELDING PENETRATIONS
- PROVIDE COOLING WATER ACTIVATION DATA
- PROVIDE ACTIVATION DATA FOR ACCELERATOR AND OTHER MATERIALS

APPROACH:

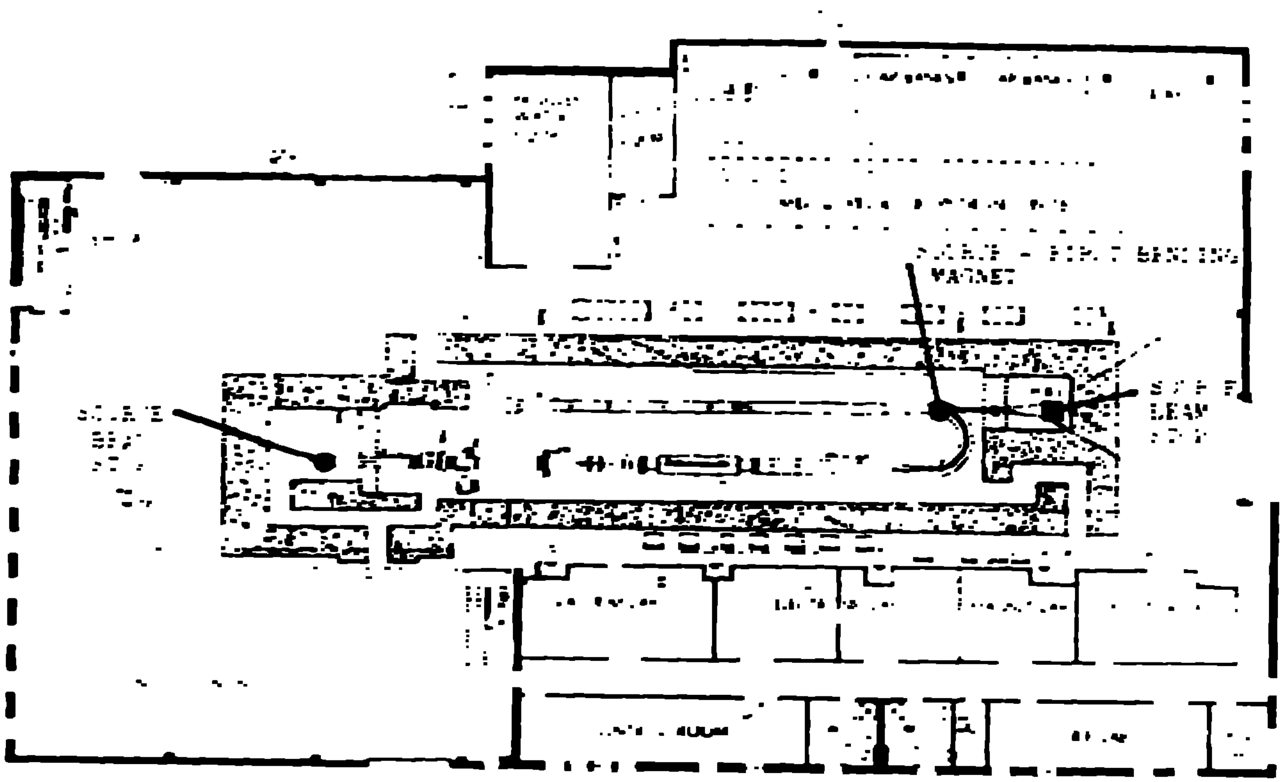
- GATHER GTA-1 PHYSICS AND BEAM LOSS ESTIMATES
- REVIEW PUBLISHED RADIATION DATA
- REVIEW THE DESIGN AND ANALYSIS CAPABILITIES OF AVAILABLE PERSONNEL
- GENERATE INTERIM REPORTS AND MEMOS OF WORK
- GENERATE A FINAL SUMMARY REPORT

RESOURCES:

- LANL APPLIED NUCLEAR SCIENCE GROUP T-2; E.D. ARTHUR, W.B. WILSON AND R.J. LABAUVE, PRINCIPALS
- HANFORD ENGINEERING DEVELOPMENT LABORATORY RADIATION EFFECTS AND SHIELDING ANALYSIS GROUP: R.J. MORFORD, F.M. MANN, PRINCIPALS
- LANL HEALTH SAFETY AND ENVIRONMENTAL DIVISION; A.J. MILLER, R.L. MUNDIS, T.E. BUHL AND B.M. BOWEN, PRINCIPALS



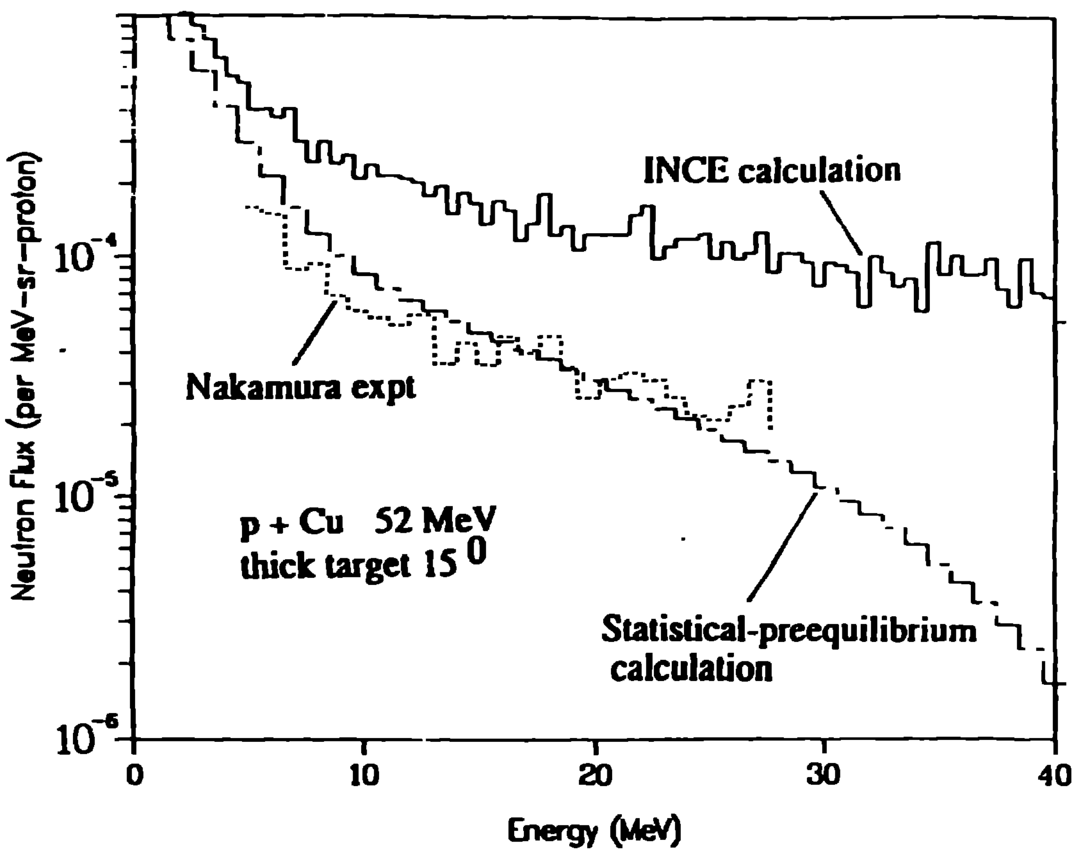
OUTLINE OF ACTIVITIES REQUIRED FOR GTA-1 SHIELDING & RADIATION SAFETY ANALYSIS



BEAM LOSSES BASED ON OPERATION AT 4 HR DAY, 4 DAY WK, 5. WK YR

SOURCE TERM LOCATIONS

• Improved methods appropriate to 50 MeV proton beams were utilized to produce neutron sources for shielding analyses.



Neutron Source Term Development for GTA Shielding

TABLE RS-1

BULK SHIELDING THICKNESS RESULTS

80 MeV Protons (5.95 x 10^{14} p/sec) 100 mA @ 0.1% D.F. 2 Sigma Thickness

Location	MCNP Isotropic Source Strength Used (n/sec)	Spectrum Used	Current	Ordinary Conc. p=2.21 g/cc	Hematite Conc. p=3.43 g/cc With Double the Cement
FIRST BENDING MAGNET	6.16 x 10^{11}	70°	5 mA ON ALUM.	7 FT.	5 FT.
H^- BEAM STOP	2.80 x 10^{13}	0°	100 mA ON CARBON	11.3 FT.	9 FT.
	4.51 x 10^{12}	70°	100 mA ON CARBON	9 FT.	7 FT.

Radiation Safety

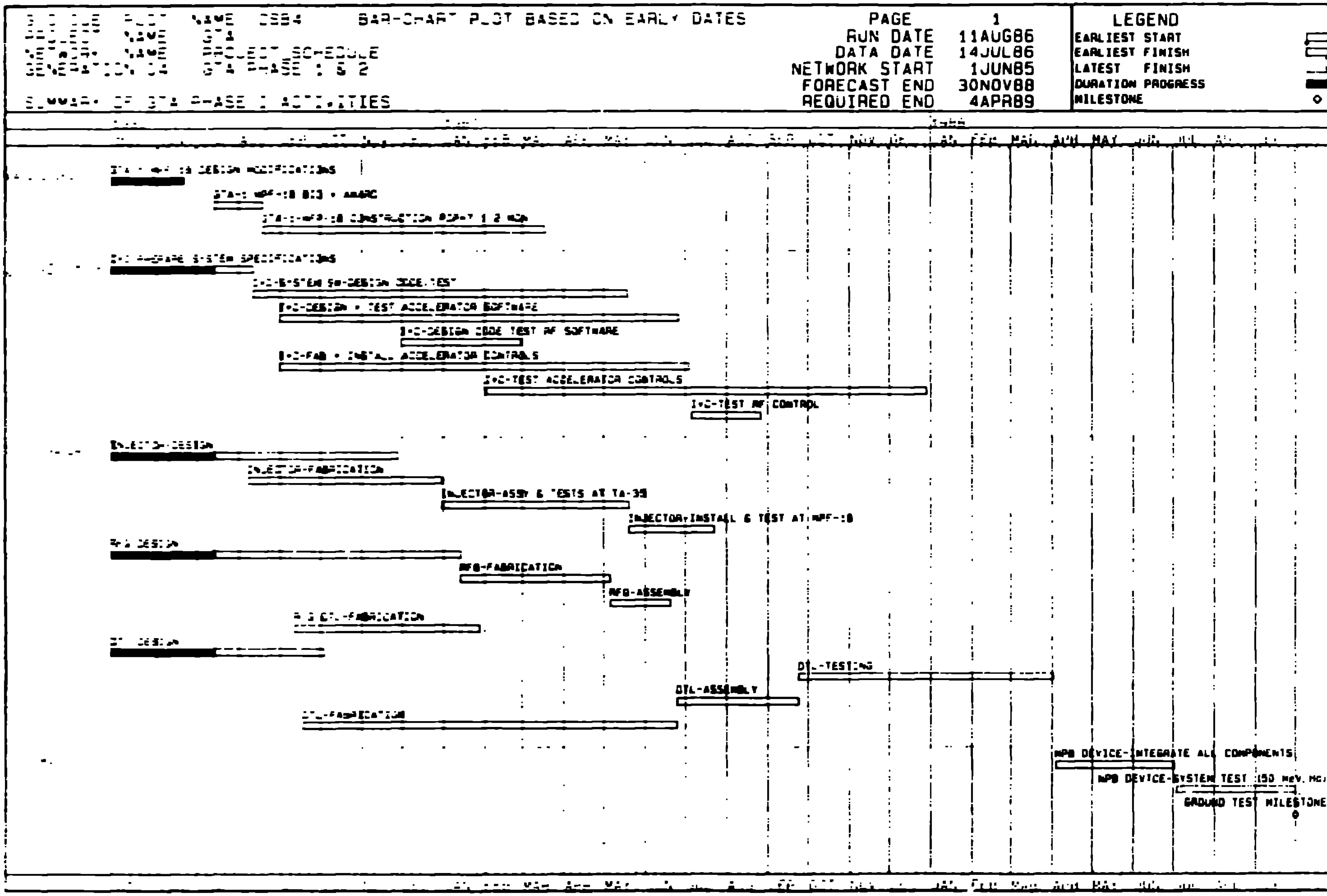
STATUS:

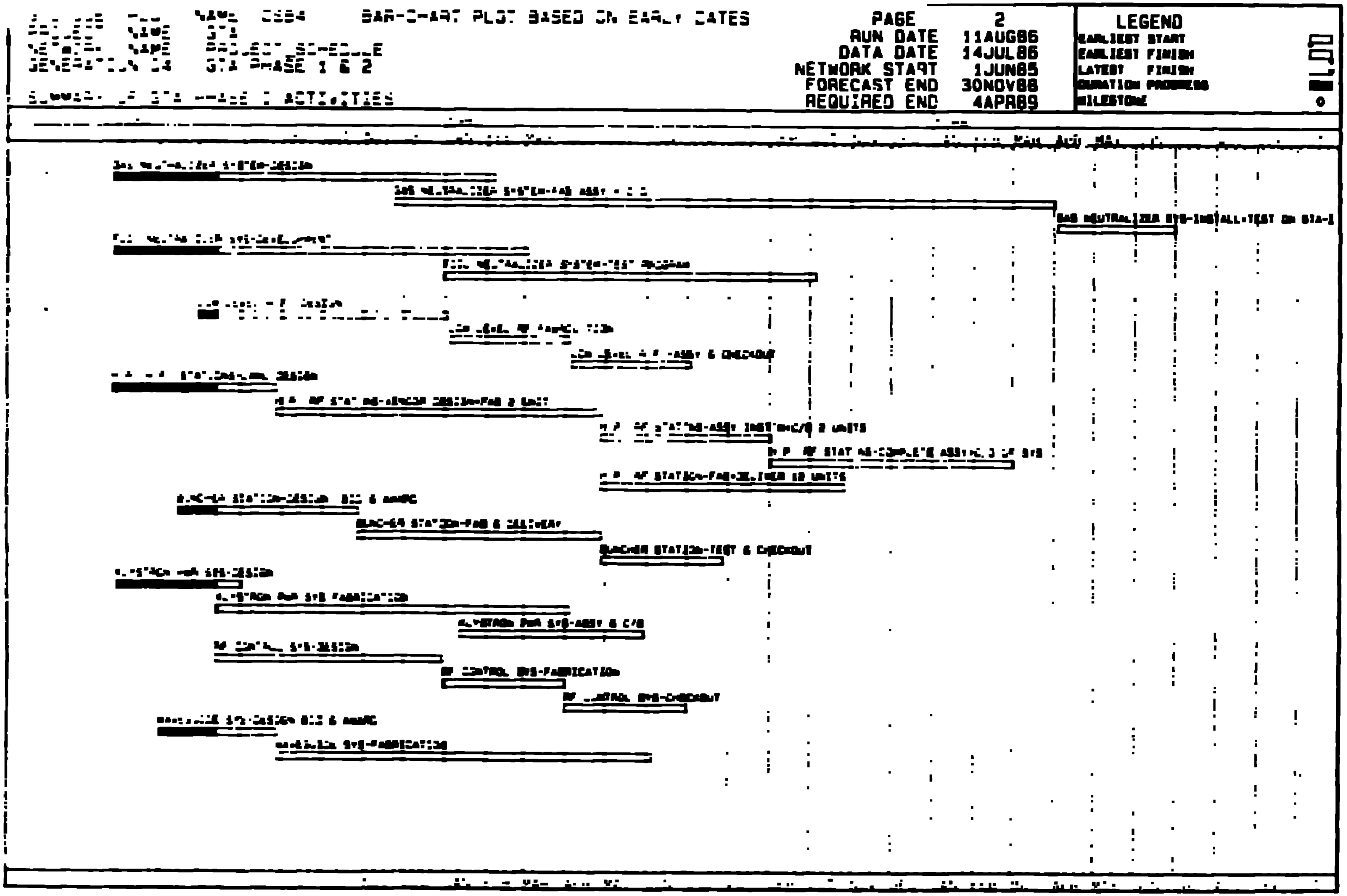
- SOURCE TERMS COMPLETED
- BULK SHIELDING DEFINED (TABLE RS-1)
- COMPONENT SHIELDING WORK UNDERWAY
- WALL SHIELDING BLOCK RFQ WRITTEN
- EXPECTED DOSES IN CONTINUOUSLY OCCUPIED WORK AREAS OF LESS THAN 1000 mREM/YR AND ATMOSPHERIC DISPERSION ANALYSIS AT NEAREST SITE BOUNDARY OF 0.025 mREM/YR

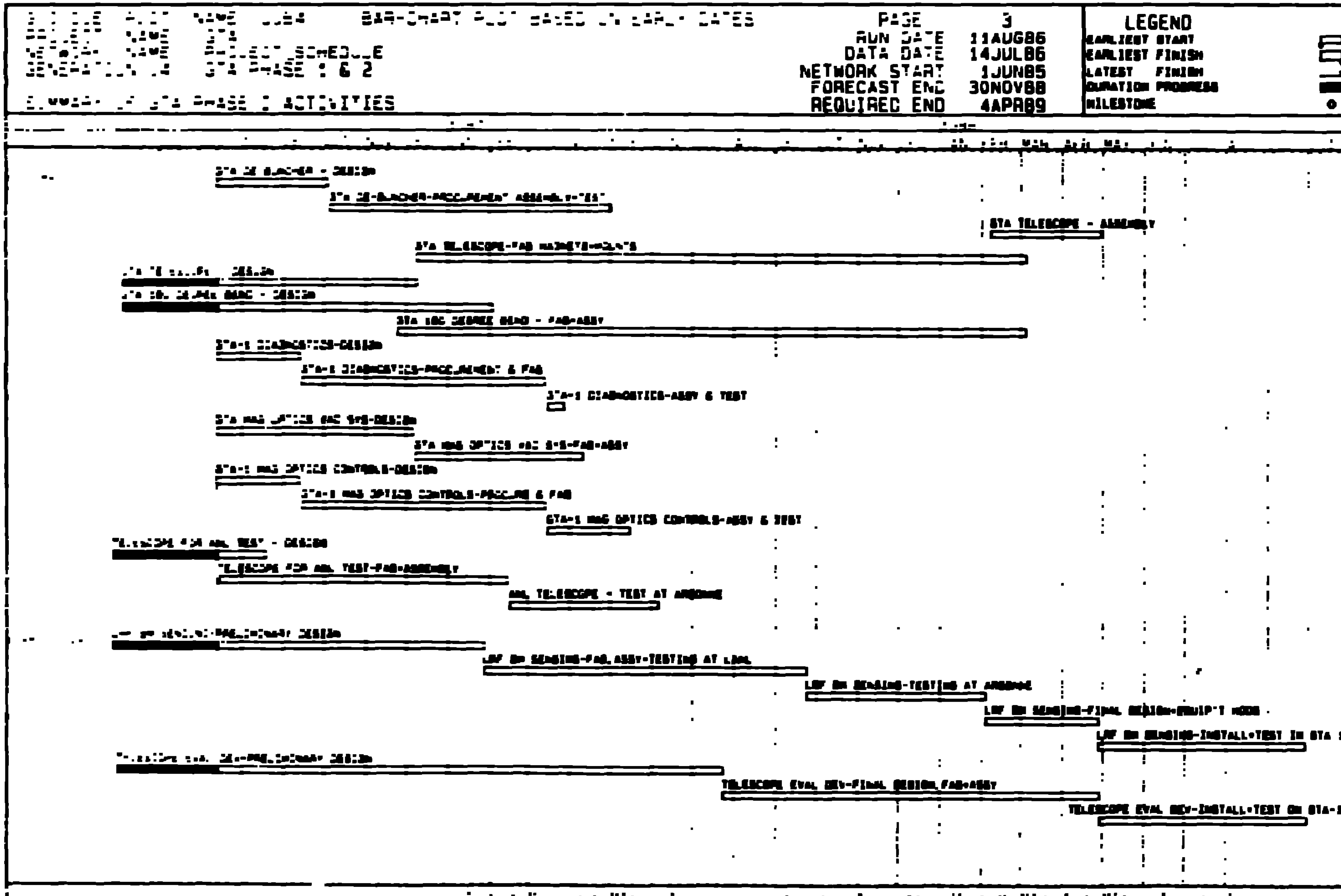
IV. SCHEDULES

Each work package in the GTA project has its own schedule, which is maintained by the work package manager; the project office has a higher level schedule. Each work package manager up-dates his schedule either weekly or bi-weekly and the project office up-dates its schedule monthly. The attached schedules show the project office schedules for the various systems.

The project office also maintains a master milestone chart that is up-dated periodically. The master milestone chart is under the configuration management system on drawing number 112-253141 E-1. It cannot be changed without going through the drawing change procedure. This chart is available from the Flight Support Office.


BAR-CHART PLOT BASED ON EARLY DATES
PROJECT NAME GTA
GTA PHASE 1 & 2
SUMMARY OF GTA PHASE I ACTIVITIES
PAGE 1
RUN DATE 11AUG86
DATA DATE 14JUL86
NETWORK START 1JUN85
FORECAST END 30NOV88
REQUIRED END 4APR89
LEGEND
EARLIEST START
EARLIEST FINISH
LATEST FINISH
DURATION PROGRESS
MILESTONE
I+C-SYSTEM SW-DESIGN CODE TEST
I+C-DESIGN + TEST ACCELERATOR SOFTWARE
I+C-DESIGN CODE TEST RF SOFTWARE
I+C-FAB + INSTALL ACCELERATOR CONTROLS
I+C-TEST ACCELERATOR CONTROLS
I+C-TEST RF CONTROL
INJECTOR-DESIGN
INJECTOR-FABRICATION
INJECTOR-ASSY & TESTS AT TA-35
INJECTOR-INSTALL & TEST AT MPF-18
RFQ-FABRICATION
RFQ-ASSEMBLY
DTL-TESTING
DTL-ASSEMBLY
DTL-FABRICATION
NPB DEVICE-INTEGRATE ALL COMPONENTS
NPB DEVICE-SYSTEM TEST
GROUND TEST MILESTONE

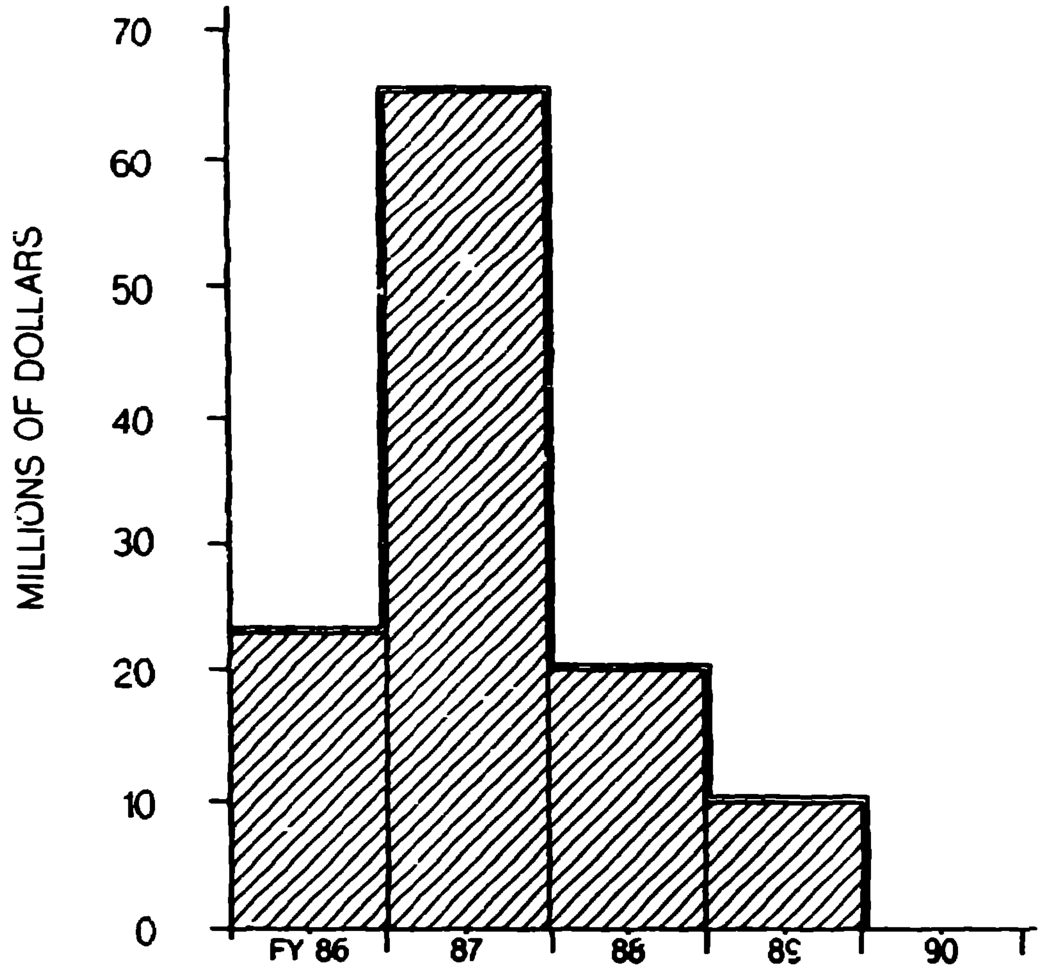

BAR-CHART PLOT BASED ON EARLY DATES
PAGE 2
RUN DATE 11AUG86
DATA DATE 14JUL86
NETWORK START 1JUN85
FORECAST END 30NOV88
REQUIRED END 4APR89
LEGEND
EARLIEST START
EARLIEST FINISH
LATEST FINISH
DURATION PROGRESS
MILESTONE
BUNCHER STATION-TEST & CHECKOUT
RF CONTROL SYS-FABRICATION


BAR-CHART PLOT BASED ON EARLY DATES
STA PHASE 1 & 2
PAGE 3
RUN DATE 11AUG86
DATA DATE 14JUL86
NETWORK START 1JUN85
FORECAST END 30NOV88
REQUIRED END 4APR89
LEGEND
EARLIEST START
EARLIEST FINISH
LATEST FINISH
DURATION PROGRESS
MILESTONE
STA TELESCOPE - ASSEMBLY
STA 180 DEGREE BEND - FAB+ASSY
STA-1 DIAGNOSTICS-ASSY & TEST
STA-1 MAG OPTICS CONTROLS-ASSY & TEST
ANL TELESCOPE - TEST AT ARGONNE
LRF BM SENSING-FAB,ASSY-TESTING AT LANL
LRF BM SENSING-TESTING AT ARGONNE
LRF BM SENSING-INSTALL+TEST IN STA 1
TELESCOPE EVAL DEV-FINAL DESIGN,FAB+ASSY
TELESCOPE EVAL DEV-INSTALL+TEST ON STA-1

V. RESOURCE REQUIREMENTS

I.A. GTA FUNDING RESOURCES

Cost estimates have been completed for GTA. The funding profile for only GTA Phase 1 is shown. Fabrication costs and facility completion produce a significant peak in fiscal 87. A reduced cost results during installation and checkout in FY 88. If additional testing using the GTA Phase 1 system is planned beyound the Ground Test Milestone at the end of FY 88 then the operating cost will be approximately $10M/year.

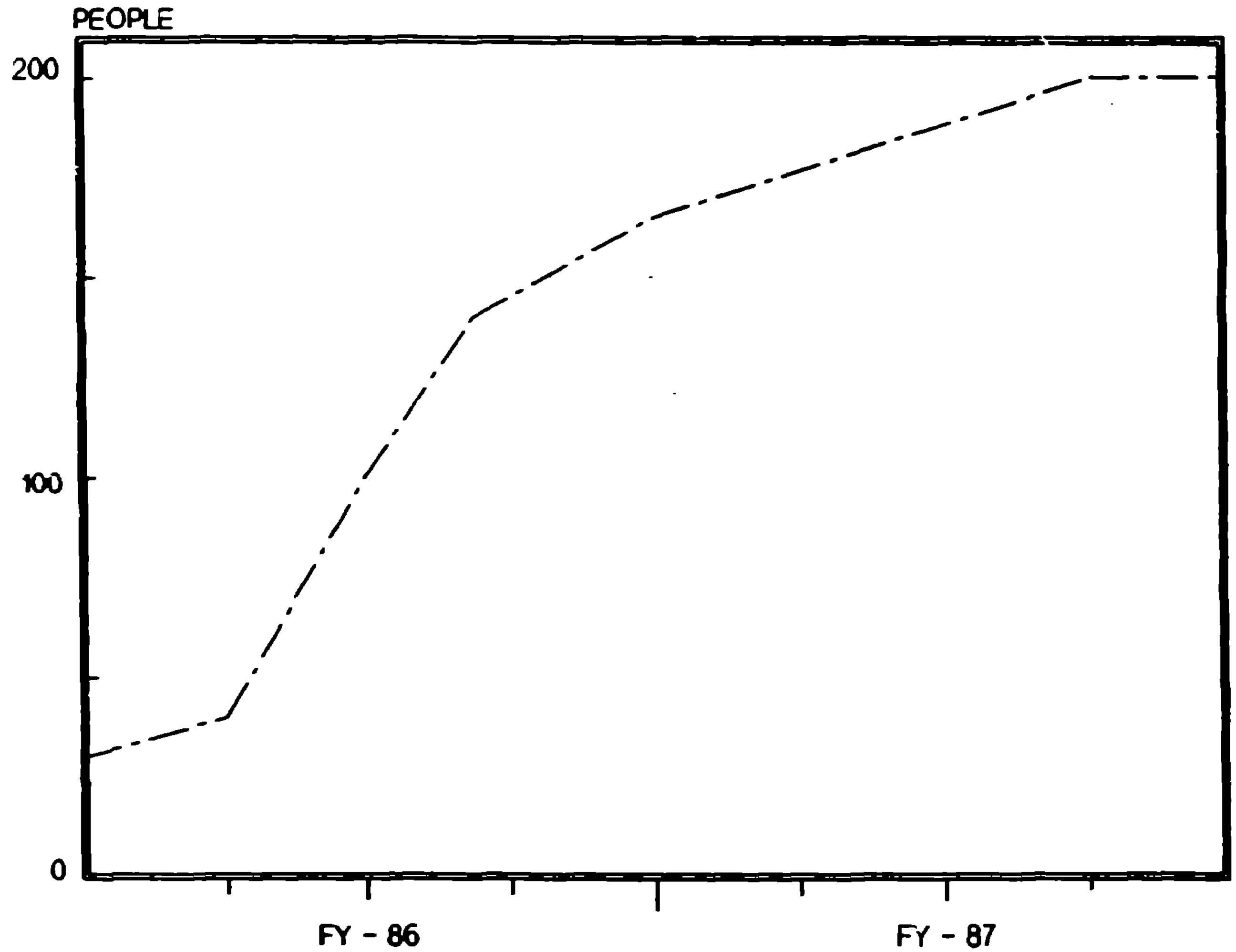


GTA PHASE I FUNDING PROFILE (COST)

V.3. **PERSONNEL RESOURCES**

Approximately 200 LANL people will be required for the entire GTA program in FY 87 and beyond. Approximately 150 are on board at the present time. These people are from many divisions and groups throughout the Laboratory as shown by the listing below:

Divisions	Groups
Engineering	ENG-2 ENG-8 ENG-9 ENG-10
Materials Management	
Electronics	E-1 E-2
Chemistry	CHM-1 CHM-3 CHM-4 CHM-5 CHM-6
Computing & Communications	C-4
Materials Science & Technology	MST-3 MST-5 MST-7
Medium Energy Physics	MP-7
Physics	P-2 P-3 P-5 P-7 P-12 P-15
Accelerator Technology	AT-1 AT-2 AT-3 AT-4 AT-5 AT-6 AT-8
Dynamic Testing	M-7
Controlled Thermonuclear Research	CTR-6 CTR-8
Theoretical	T-2
Design Engineering	WX-4
Energy	Q-13
Analysis & Assessment	S-3



GTA - STAFFING REQUIREMENTS

APPENDIX A. GTA PHASE 1
BASELINE SYSTEM SPECIFICATION SUMMARY

Table 3.2
GTA PHASE 1 SYSTEM SPECIFICATIONS

Particle	H
Output Energy	50 MeV (nominal)
Accelerator Output Beam Current (H^-)	100 mA (nominal) 20 mA (tune up capability)
Output Beam Current (H°)	45 mA (nominal)
Output Current Repeatibility (H°)	±5%
Output Beam Radius (H°)	<3.0 cm rms (1σ)
Output Beam Shape	Ellipse with x & y diameter ratio between 0.8 and 1.0
Output Beam Divergence (H°)	$\leq$25 μrad (θ/2) rms
Output Beam Deflection (H°)	0 to 0.5°, one plane
Steering Accuracy	<10 μrad
Operating Frequency	425 MHz (nominal)
Operating Frequency Stability	±10 kHz
Duty Factor	0.1% (operating) 5% (accelerator design value)*
Beam Pulse Width (variable)	30 to 300 μs (operating) 2 ms (accelerator design value)*
Pulse Repetition Rate	Accelerator compatible with 0.1% DF, NPB device 3 Hz maximum (also single pulse capability)
Normalized RMS Accelerator Output Beam Emittance (H^-)	0.02 π cm-mrad (nominal at 100 mA)
Operating Ambient Temperature	Nominal room temperature
RFQ & DTL Temperature Stability	±0.5° F (about set point)
Operational Requirements	4 hours/day 4 days/week 46 weeks/year (736 hours/year) for TBD years (~8 x 10^6 pulses/year at 3 Hz)
Configuration	180° bend (Design compatible with hinge in DTL & telescope)
Size	Basic accelerator design compatible with single shuttle launch (fit withi 56'x14'x14'shuttle bay) (<3.2 m between axes of the 180° bend
Beam Height	1.52 m (60")

'stem to be installed in TA-53, MPF-18

Installed hardware will include complete NPB system through and including H° beam stop.

Hardware will be space qualifiable wherever possible but is not required to be space qualified.

* Injector and LEBT, RFQ, buncher, RGDTL, 50 MeV DTL, vacuum system and cooling system shall be designed to fulfill the 5% duty factor and 2 ms pulse length requirement of GTA Phase 2.

Table 3.6
GTA PHASE 1 INJECTOR SPECIFICATIONS

<u>Ion Source</u>	
Ion	H^-
Ion Source Type	Dudnikov (small angle source)
Pulse Width (variable)	30-300 μs (operating), 2 ms (design)
Duty Factor	0.1% (operating), 5% (design)
Repetition Rate	Consistant with 0.1% DF (single pulse capability required)
Output Current	150 mA (nominal)
Current Variability	5% rms
Current Repeatability	±2%
Delay time from initiation pulse to 10% current risetime	TBM μs
Cooling Requirement	6 kW (average)
<u>LEBT</u>	
Output Energy	100 keV (nominal)
Output Current (H^-)	>120 mA
Transmission	>90% at full current
Normalized rms Output Beam Emittance (at 100 keV)	0.017 π cm-mrad (rms normalized) (at full current)
Focus System	Permanent magnet (samarium cobalt)
Beam Space-Charge Neutralization	Xenon Residual Gas
Beam Matching	Minimum angle 41 mrad, Beam Waist radius 1.0 mm
Vacuum Requirement	$<1 \times 10^{-5}$ torr Xe $<1 \times 10^{-6}$ torr H_2
Cooling Requirement	1.0 kW (average)
<u>Injector Totals</u>	
Length	<1.1 m
AC Power Requirements	TBD kW at 208 volts, 3Ø
Total Cooling Capability Required at Injector Location	16 kW

Table 3.7

GTA PHASE 1 RADIO FREQUENCY QUADRUPOLE SPECIFICATIONS

Operating Frequency	425.000 ±0.010 MHz
Operating Frequency Stability	±10 kHz
Operating Frequency Tuning Range	±20 kHz
Injection Energy	100 keV (nominal)
Output Energy	2.07 MeV
Input Current	120 mA
Output Current	106 mA
Current loss at nominal output	<20 mA
Duty Factor	0.1% (operating), 5% (design)
Normalized rms Output Beam Emittance	<0.019 π cm-mrad (nominal)
Output rms Beam Radius	<TBD cm
Emittance Growth	<0.002 π cm-mrad
Total Length	<2.65 Meters
RF Drive	Loop Coupled
RF Field Dipole Content	<5%
RF Field Flatness (longitudinal)	<5%
Surface Electric Field	≤36 MV/m (1.8 x Kilpatrick)
Beam Matching	Buncher
Vacuum Requirement	$<1 \times 10^{-6}$ Torr
Operating Temperature	__° F
Temperature Stability	±0.5° F
Cooling Requirement	2 kW
RF Power Requirement	528 kW (nominal)
Mechanical Alignment Tolerance	±0.01 mm (5×10^{-4} in.)

Table 3.8

GTA PHASE 1 BUNCHER SPECIFICATIONS

Operating Frequency	425 MHz (nominal)
Frequency Stabilization	Slug Tuner
Output Current	>100 mA
Output Beam Radius	<TBD cm
Duty Factor	0.1% (operating), 5% (design)
Operating Gradient	2.5 MV/m (nominal)
Length	2.5 $\beta\lambda$ (TBD m)
Beam Matching	Ramped Gradient DTL
Vacuum Requirement	<1 x 10^{-6} Torr
Cooling Requirement	Minimal
RF Power Requirement	30 kW peak (ATS Type)

Table 3.9

GTA PHASE 1 DRIFT TUBE LINAC (DTL) SPECIFICATIONS

Operating Frequency	425 ±0.010 MHz
Input Energy	2.0 MeV (nominal)
Output Energy	50.0 MeV (nominal)
Output Momentum Spread	<0.001
Output Beam Current	100 mA (nominal)
Beam Loss at Nominal Current	<1%
Output Beam Radius	<0.1 cm (2σ)
Duty Factor	0.1% (operation), 5% (design)
Normalized rms Output Beam Emittance	0.02 π cm-mrad (nominal)
Emittance Growth	<0.001 π cm-mrad
Ramped Gradient, 1st Tank	2 to 4.4 MV/m (nominal)
Accelerating Gradient Range	4.4 to 5.0 MV/m for 6 remaining tanks
Number of RF Drives/Tank	4 (Maximum)
RF Drive	Loop coupled (500 kW)
Frequency Stabilization	Tuner
RF Field Stabilization	Post Couplers
Quadrupole Focusing	Permanent Magnet (neoydenium-iron)
Length	
To Simulated Hinge Point	<12 Meters (nominal)
End-to-end	<16.2
Vacuum Requirement	<1 x 10^{-6} Torr
Operating Temperature	__° F
Temperature Stability	±0.5° F
Cooling Requirement	12 kW (average) water cooled
RF Power Requirement	(see RF system requirement)
Number of tanks	7
Number of Drift Tubes	109
Drift Tube Mechanical Aligment Tolerance	±TBD mm
Phase Ellipse Parameters	TBD
Sign of Last Quadrupole	TBD

Table 3.10

GTA PHASE 1 HIGH ENERGY BEAM TRANSPORT (HEBT) SPECIFICATIONS

Particle	H^-
Beam Energy	50 MeV (nominal) and 7, 15, 23, 31, 39, and 47 MeV for installation checkout
Beam Current	100 mA (nominal) & 20 mA (tune-up)
Beam Energy Spread	<.001
Input Beam Radius	<1 mm (2σ) nominal
Output Beam Radius	22 cm (3σ)
HEBT Operating Pressure	10^{-6} torr
HEBT Operating Temperature	Ambient
HEBT Cooling	5 kW
Transport System Type	Electromagnetic quadrupole doublet

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Table 3.11

GTA PHASE 1 H^- BEAMSTOP SPECIFICATIONS

Particle	H^-
Input Beam Energy	50 MeV
Input Beam Current	100 mA
Input Beam Diameter	41 cm (3σ)
Beamstop Type	0.5 cm graphite bonded to copper
Beam-spot Size on Beamstop	41 x 47 cm (3σ)
Slant Angle	60°
Cooling Requirement	5 kW
Vacuum Requirement	$<10^{-6}$ torr
Beamstop Power Dissipation	20 w/cm^2 (maximum)

Table 3.12

GTA PHASE 1 BEAM MAGNETIC OPTICS SPECIFICATIONS

(SUMMARY)

<u>Input Beam Assumptions</u> (Output of DTL)	
Energy	50 MeV
Momentum Spread	<±0.05%
Current	100 mA, H^- (nominal), 20 mA tune-up
Emittance	0.02 π cm-mrad, rms normalized
Beam Radius	<1.25 mm rms
<u>Output Requirements</u>	
Clear Aperture	30 cm diameter
Beam Steering Range	0 to 0.5° in one plane
Beam Expansion Ratio	~ 25
Focusing Range	1 - 100 km
Beam Radius	3 cm rms nominal
Beam Divergence (after steering)	≤25 μrad, rms (normalized)
Beam Magnetic Optics Divergence Contribution	
Chromatic Aberration (at 0.5° off axis)	<1 μrad
Aperture Aberration	TBD μrad
Space Charge Growth	TBD μrad
Beam Direction	180° from input direction
Output current (H^-)	100 mA nominal
Current Loss	<1%

NOTE: Apertures 10 times rms beam size except output lens where it is 5

(d)

Table 3.13

GTA PHASE 1 DETAIL BEAM MAGNETIC OPTICS SPECIFICATIONS

5.1 Matching Section

Emittance Growth	TBD
Output Beam Radius	<1.25 mm (rms)
Maximum Length	<2 m
Vacuum Requirement	$<10^{-6}$ torr
Cooling Requirement	none

Must be able to match to 180° bend or HEBT and H^- beamstop as required

5.2 180° Achromatic Turning System

Emittance Growth	<TBD%
Output Beam Radius	<1.25 mm rms
Effective Bend Diameter (centerline to centerline)	<3.2 m
Mechanical Alignment Tolerance	TBD mm
Clear Aperture	
Dipole	5 cm diameter
Quadrupole	3 cm diameter
Outside Diameter (Magnet)	15 cm
Magnet Material	TBD
Magnet Type	First magnet is electromagnet, remainder are permanent magnets, with electromagnet trimmers
Vacuum Requirement	$<10^{-6}$ torr
Cooling Requirement	10 kW

Table 3.13 (continued)

5.3 Beam Expanding Telescope	(7.5 m nominal length)
Vacuum Requirements	$<1 \times 10^{-5}$ torr
Cooling Requirements	TBD
Divergence	<25 µrad
Eyepiece	
Clear Aperture	5.0 cm diameter
Focus	Variable, TBD
Tilt with respect to objective lens	
Angular range	TBD µrad
Accuracy	TBD µrad
Displacement with respect to objective lens	
Range	fixed
Accuracy	±5 mm
Magnet Type	Permanent magnet, electromagnet trimmer
Magnet Material	TBD

Table 3.13 (continued)

GTA PHASE 1 DETAIL BEAM MAGNETIC OPTICS SPECIFICATIONS

<u>Objective</u>	
Clear Aperture	30 cm diameter
Output Beam Radius	<3.0 cm
Focus	Variable, 1-100 kM
Magnet Material	TBD
Magnet Type	Permanent magnet with electromagnet trimmer
<u>Steering Magnet</u>	
Output Beam Radius	<3.0 cm
Clear Aperture	30 cm diameter
Steering Range	0 to 0.5° in one plane
Coil Current Control	±TBD%
Steering Accuracy	<10 μrad
Jitter	TBD
Position Tolerance	TBD
Position Stability	TBD
Slew Rate	1 degree/s
Vacuum Requirements	$<10^{-5}$ torr
Cooling Requirements	none
Magnet Type	Electromagnet

(all)

Table 3.14

GTA PHASE 1 NEUTRALIZER PERFORMANCE SPECIFICATIONS

Input Particle	H^-
Output Energy (H^o)	50 MeV (nominal)
Input Beam Current (H^-)	100 mA
Neutralization Efficiency ($H^o/_{H^-}$)	>45%
Neutralization Efficiency Uniformity	±TBD%
Neutralization Efficiency Time Dependance	TBD
Output Beam Divergence (H^o)	25 μrad ($^{\theta}/_{2}$)rms
Neutralizer Contribution to Divergence	<3 μrad
Duty Factor	0.1%
Beam Pulse Width (variable)	30 to 700 μs
Pulse Repetition Rate	≤3 Hz
Beam Steering	0 to 0.5°, one plane
Neutralizer Bore	30 cm diameter
Output Beam Diameter	5.0 cm rms
Baseline Design Gas	Argon
Gas Pressure	2 x 10^{-2} torr
Target Length	100 cm
Target Thickness	4.5 μgm/cm^2
Gas Pulse Time Constant	30 ms
Vacuum Requirement	TBD
Cooling Requirement	25 gpm @ 70° ±5° F inlet temperature
Electrical Power Requirements	60 kW, 208 V-3ø-60 Hz
External Magnetic Field	TBD
Magnetic Shielding	<30 mG/m
Gas Load into	
Beam Magnetic Optics Volume	<10^{-5} torr
Beam Sensing Volume	<10^{-6} torr
Total Length	~6m

Table 3.15

GTA PHASE 1 BEAM SENSING PERFORMANCE SPECIFICATIONS

Beam Sensing	
Measure direction of H° beam	±10 μrad
Temperature Control Range	±0.5° F
Vacuum Requirement	$<10^{-6}$ torr
Beam Scoring	
Beam Intensity	TBD
Beam Profile (intensity vs x&y)	10% FWHM
Beam Energy Spectrum	±10%
Beam Flux	TBD
Beam C roid Accuracy	TBD mm
Temporal Resolution	±TBD μs
H° Beamstop	
Particle	H°
Input Beam Energy	50 MeV
Input Beam Current (H°)	50 mA (nominal)
Input Beam Diameter	TBD
Beamstop Type	>0.5 cm graphite bonded to copper
Slant Angle	TBD°
Beam-spot size on Beamstop	not less than 2.0 cm (1σ)
Beamstop Power Dissipation	<200 watts/cm² average (200 kW/cm² peak)
Vacuum Requirement	$<10^{-6}$ torr
Cooling Requirement	5 kW
H^{+} Beamstop	TBD
Cooling Requirement	TBD
H^{-} Beamstop	TBD
Cooling Requirement	TBD
Drift Tube	
Diameter	51 cm (20")
Length	TBD m

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Table 3.16
GTA PHASE 1 RF SYSTEM PERFORMANCE SPECIFICATIONS

Frequency	425 MHz
Bandwidth (1.0 dB Points)	±2.5 MHz
RF Power Required (peak)	MW
RFQ	0.506
Buncher	0.050
DTL 1 (RGDTL)	0.851
DTL 2	1.726
DTL 3	1.686
DTL 4	1.705
DTL 5	1.632
DTL 6	1.610
DTL 7	0.848
Momentum Compactor	0.125
Total	10.739 (no margin for overdrive)
Maximum Beam Current Fluctuation Accomodation	≤5%
Pulse Length (variable)	30-350 µsec
Repetition Rate	Compatible with 0.1% DF
Duty Factor	0.1% (operating) ***
Amplitude Control	±0.5%
Phase Control	±0.5°
Load Reflected Power	Mismatches at start/end of pulse
Input AC Voltage	(480 volts, 3 phase) 13 kV?
Input AC Current	TBD
Tube Type *	Klystron
Tube Output Connector	WR 2100 Waveguide
Accelerator Structure	6-1/8" Coaxial Line
Input Connector	Loop Driven
Power Level per Drive Loop **	500 kW (nominal) (1 MW?)
Controls	Compatible with Computer Control
Cooling Requirement	98 kW

* Provision will be made to test 500 kW solid state and klystrode RF units.

** One klystron driven two ports

*** Provisions for reconfiguring RF system to drive one DTL tank at 5% duty factor.

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ROUGH DRAFT

APPENDIX B

SAFETY / RISK ASSESSMENT

GROUND TEST ACCELERATOR PHASE I

ROUGH DRAFT

Table of Contents

Table of Contents (cont.)

I. Introduction

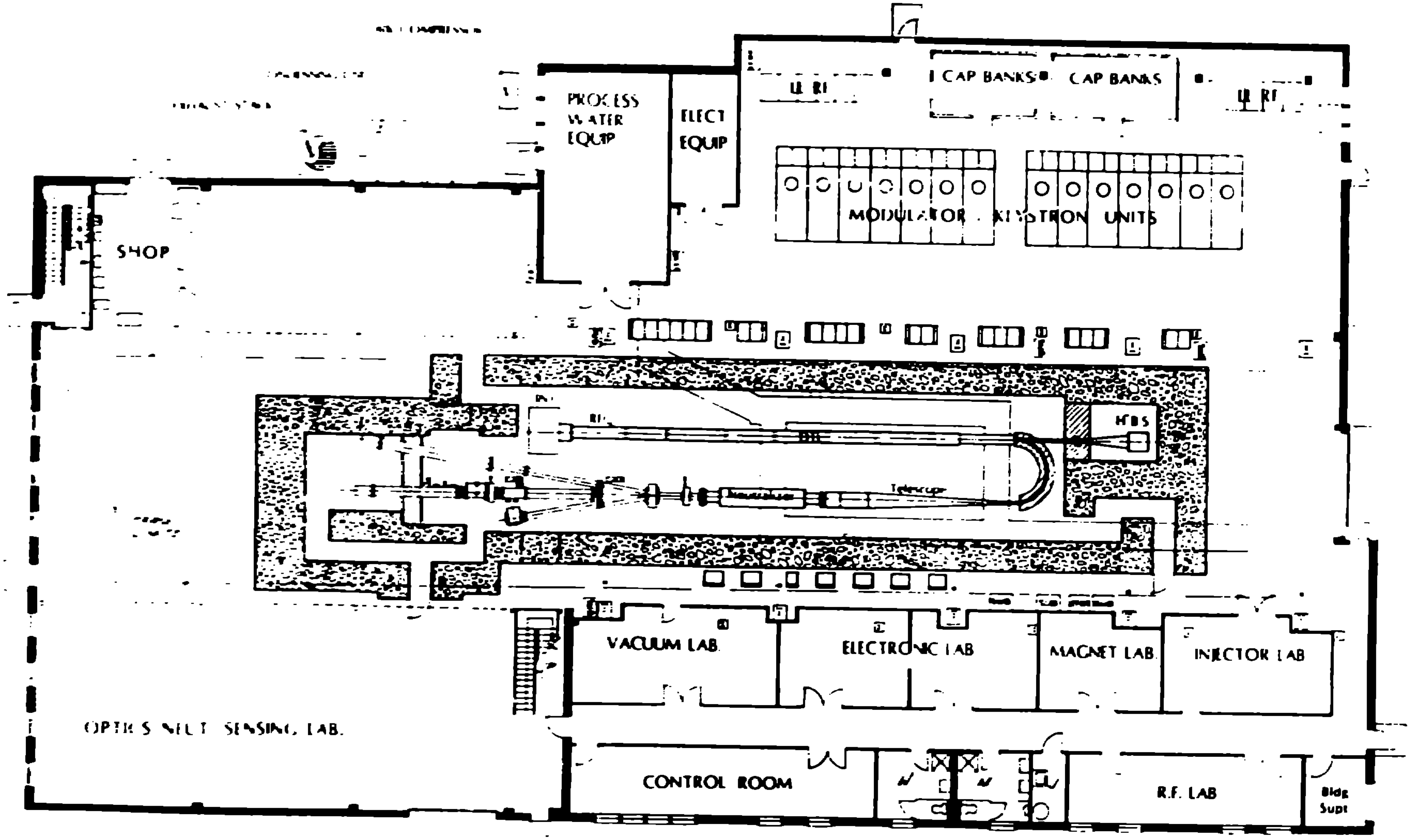
A. Description of Associated Facilities and Equipment

The Ground Test Accelerator-1 (GTA-1) is a key part of the U.S. Neutral Particle Beam (NPB) weapons program. That program will assess the feasibility of using neutral particle beams as directed energy weapons. The NPB program has recently been incorporated into the Nation's Strategic Defense Initiative. GTA-1 will support the Integrated Flight Experiment (IFE-1) and provide hardware, design and experimental knowledge for GTA-2.

GTA-1 is an accelerator based on technology developed by the Laboratory's AT Division. It is located within Laboratory boundaries at TA-53. Major operating parameters are listed below. A more detailed description appears in Appendix A to Los Alamos NPB Integrated Space Experiment Point Design Study Report dated January 10, 1986.

Accelerated Particle	H^-
Output Energy	50 MeV
Output Beam Current (H^-)	100 mA
Output Beam Current (H°)	45 mA
Duty Factor	0.1%
Beam Pulse Width (variable)	30 to 300 us
RF Frequency	425 MHz

Figure I-1, I-2 and I-3 show facility layout. The accelerator and associated systems are housed in an existing building and its new square foot addition that has a steel frame and corrugated steel siding. Office, laboratory and support area walls are of metalstud-gypsium board construction.



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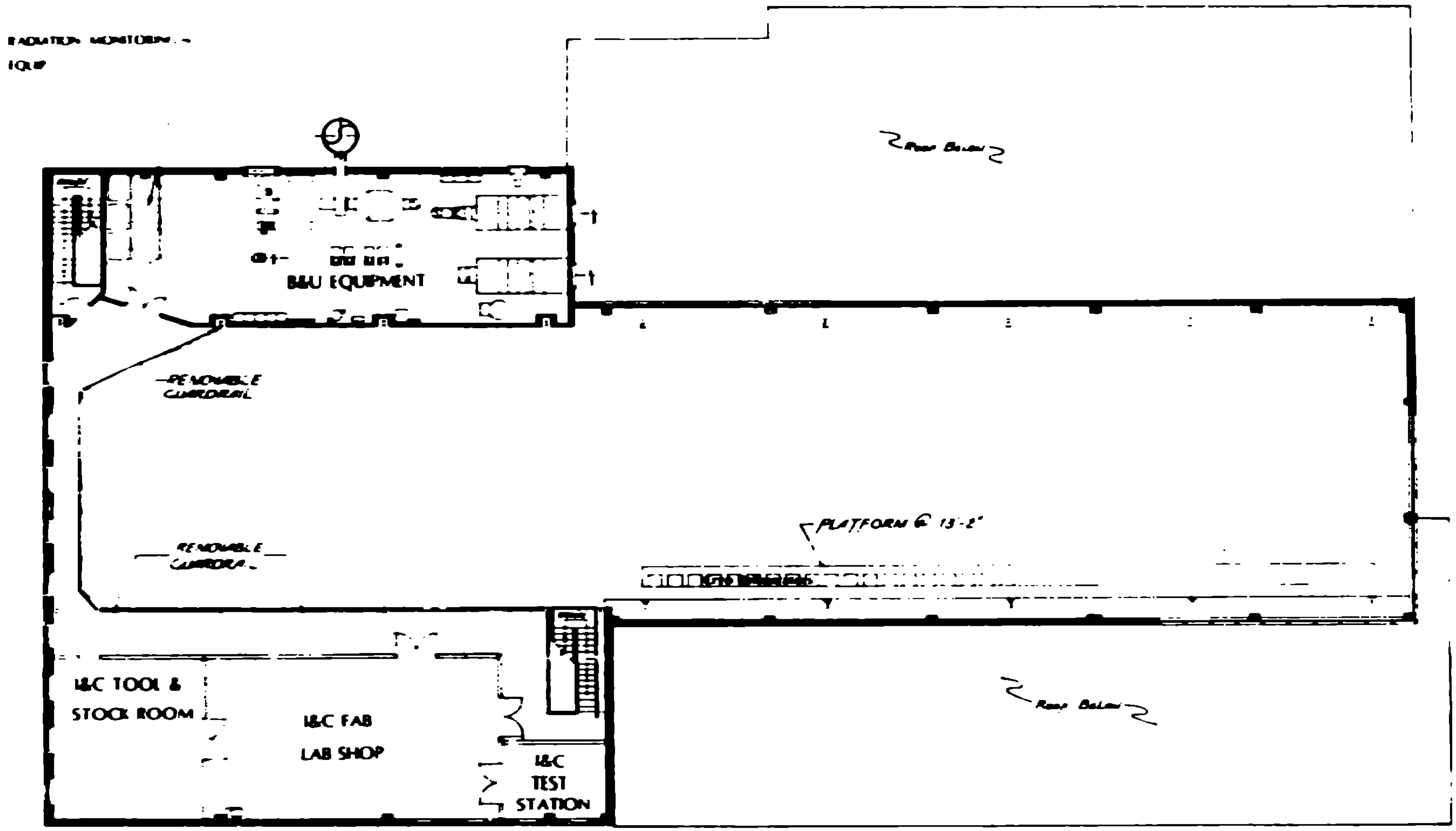
GTA-1 FACILITY FIRST FLOOR



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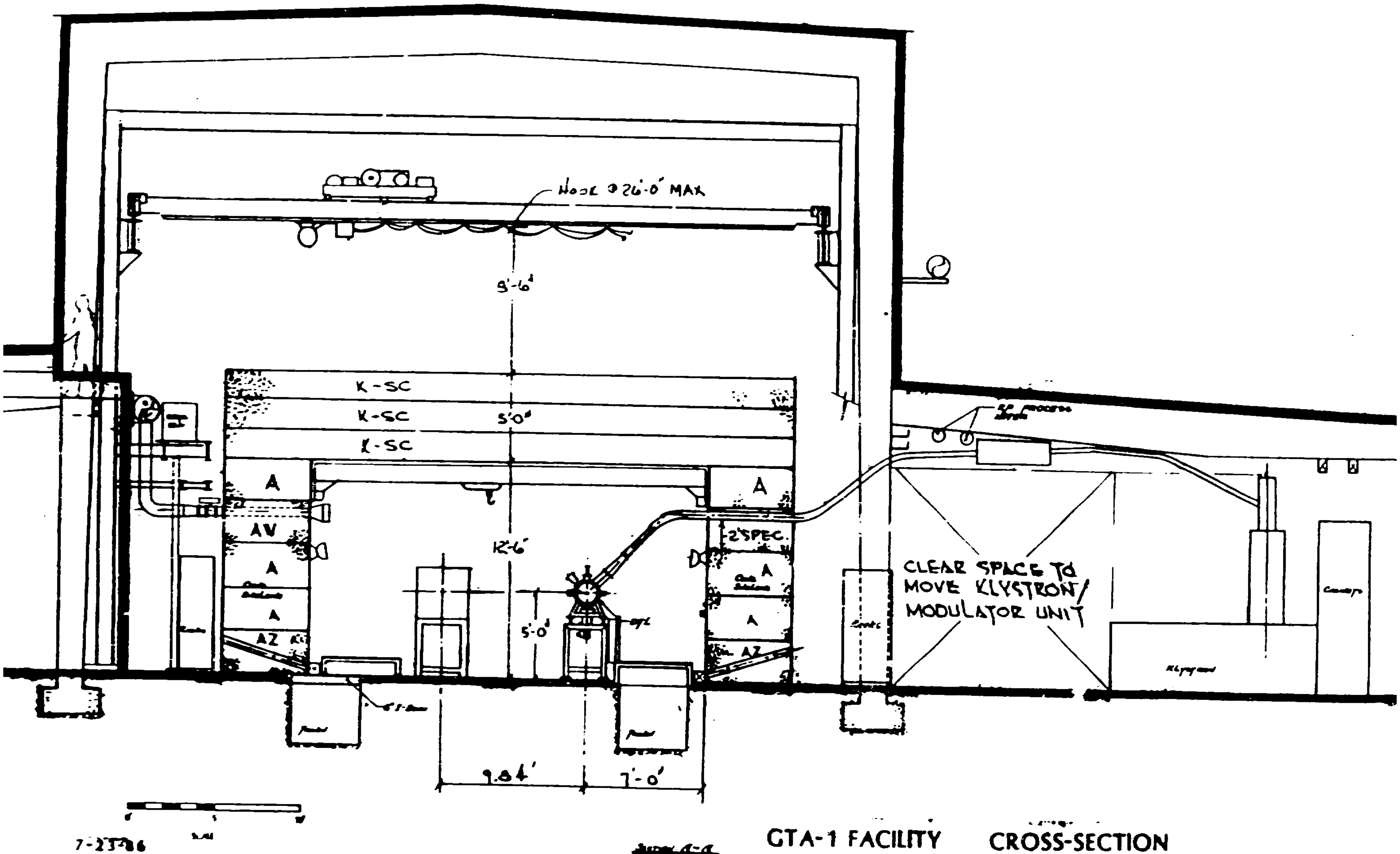
GTA-1 FACILITY —— SECOND FLOOR



GTA-1 FACILITY CROSS-SECTION

Particle acceleration begins at the injector in which H^- particles are generated and accelerated to 100 keV. The injector is followed by a radio frequency quadrupole (RFQ) accelerating section that increases beam energy to 2.0 MeV. The final accelerating assembly is a drift tube linac (DTL) composed of seven DTL tanks. At the end of the DTL the beam can continue straight ahead to the H^- beam stop (BS) or be switched to a 180° turning section. The H^- beam stop is used for tuning the accelerating sections. Following the turning section the beam is expanded in a telescope to 25 cm diameter and passes through steering magnets to the neutralizer. In the neutralizer about 50% of the H^- particles are converted to H° particles, 25% remain H^- and 25% become $H+$. In the beam sensing region the direction and divergence of the neutral beam is measured. Finally, the beam strikes the water-cooled H° beam stop which contains a beam scoring system.

Installation and experimental operations will be the responsibility of a Project team.

B. Description of Operations

Objectives of the GTA-1 Project are:

- Validate basic design parameters ISE-1
- Demonstrate performance of selected ISE-compatible components
- Provide an engineering test bed for component development
- Provide a mechanism for transferring technology to industry
- Provide a system for testing industry-developed components.

The accelerator and associated systems shown in Figure I-1 will be installed and tested in a sequence beginning with the injector and ending with the H° beam stop. When the system is fully operational it will be used to satisfy the objectives listed above.

The operations schedule is planned to be an average of four hours per day, four days per week, and 46 days per year (736 hours per year).

II. Description of Hazards

A. Hazards

1. Ionizing Radiation from Structure and Shielding

Within the facility the accelerated H^- beam will pass through a magnetic optics section, expanding bending, shaping and steering magnets, a neutralizer (producing H°, H^-, and $H+$ particles. And finally into a beam stop that will safely dissipate the particle beam energy. Throughout this system, but especially in high-energy regions and in the beam stops, high-energy neutrons will be generated. These include a high flux of neutrons with energies up to 50 MeV but having an average energy of about 1 MeV. An approximately equal intensity of prompt gamma rays having a maximum energy of about 4 MeV will also be produced. High energy neutrons will activate materials throughout the accelerator vault and beam stop vault. Low level activation of cooling water is also likely to occur. The magnets will be a source of residual radiation. The magnetic optics neutralizer and beam sensing sections of the GTA facilities can be made of aluminum, thus reducing activation in the general structures. The beam stops, the greatest sources of residual radiation, will be made primarily of graphite, copper and aluminum. Isolation, shielding, and limited access will be used to minimize radiation exposure from the beam stops. Copper alloys and copper plating will be used to minimize rf losses and to maximize heat removal in certain locations.

At the 50 MeV end of the DTL, the highest neutron fluxes are expected from particle losses in the matching section of the magnetic optics; the fluxes generated will also have the highest energy spectrums. The high-energy spectrums are important because many of the activation reactions are threshold reactions. Maximum allowable exposures are those contained in DOE Order 5480.11. During normal beam operation the air in each vault and beam stop will be stagnant. When the beam is off, air from these [illegible], will be vented through a high-efficiency (99.97%) particulate air (HEPA) filter bank and an exhaust stack. Personnel access will be allowed only when ventilation is operational and safe radiation levels have been achieved.

The Los Alamos National Laboratory Applied Nuclear Science Group (T-2) in collaboration with the Radiation and Shielding Analysis Group of the Hanford Engineering Development Laboratory, are doing a shielding study and will provide engineering data necessary to design shielding to meet exposure criteria. The accelerator will be surrounded by normal and high density concrete stepped stack-block shielding that can be quickly moved by an overhead crane for reconfiguration of the accelerator or for maintenance work. Preliminary bulk shielding thickness is analyzed in letter, Morford to Cole, "ATSU, 100 MeV Linac Shielding 10/20/85". Shielding thickness required for the GTA-1 beam stop is approximately 8 ft. of high density concrete. Cracks in the stack up block will be sealed to prevent leakage of radioactive air from the vault.

The policy of the Los Alamos National Laboratory is that employee and public exposure to radiation and radioactive materials will be kept to the lowest level technically and economically feasible and always less than the standards for radiation workers (Health and Safety Manual, Administrative Requirement 3-1). The "as low as reasonably achievable" (ALARA) principle will be adhered to in all activities to minimize operational exposures.

2. Emissions

No nonradioactive emissions are anticipated which would require regulation under New Mexico Air Quality regulations 702 and 703. No emissions will be produced requiring regulation under Prevention of Significant Deterioration (PSD) rules.

Airborne emissions will consist of activated air discharged through HEPA filters to the atmosphere at intermittent times. Filters will be tested in place to assure 99.97% efficiency. The only way to dispose of activated air is to hold it for radioactive decay to acceptable levels and then vent it to the atmosphere. Any activated gases will be vented so that resulting doses do not exceed the DOE occupational exposure RPS (5480.11 proposed revision) of 0.5 mrem/hr in continuously occupied work areas. No activated air will be circulated or exhausted during beam operations.

Preliminary air activation data was computed for the ATSU facility (the previous name for the GTA-50 MeV accelerator) based on an 8 hour/day irradiation time and various decay times. (Ref. letter R. J. Morford, radiation and Shield Analysis, Westinghouse Hanford Company, to T. R. Cole, AT-4, Los Alamos at the Los Alamos National Laboratory, received April 12, 1985). The code used by Westinghouse Hanford Co. to calculate the production and quantity of isotopes for GTA-1 is REAC (Reaction Activation). The REAC code is used for activation calculations. It has four basic libraries which makes input very straight-forward. The libraries are: (1) material composition, (2) multi-group flux, (3) multi-group cross sections, and (4) radionuclide decay. This code is the best available at this time for high energy neutron activation and is widely used. Many other codes are used as required for specific parameters.

The code was rerun at the Los Alamos National Laboratory using the average beam intensity for a nominal 8-hr running day and various decay times to more accurately reflect the production that can be expected for each isotope. The operating day for GTA-1 is four hours and the duty factor is 0.1%. The reduction in run time and duty factor reduce the annual dose to a member of the public at 1000 m from about 0.30 mrem in the Dewart-Buhl report to 0.025 mrem. Dose scales with duty factor but not with running time because of different times to saturated activity. Table II-1 lists air concentration and annual dose by radionuclide for GTA-1 operating parameter.

Atmospheric dispersion analysis for the ATSU facility indicated that the expected annual whole body dose received at the nearest site boundary for routine release (8 hr day 4 day/wk irradiation time, 1% DF) was 0.3 mrem. (Ref. Appendix A, memorandum, Dewart and Buhl to Olinger, Routine Releases from the Accelerator Test Stand Upgrade, /25/85), attached. The nearest site boundary is the fence bordering State Road 4 (Main Hill Road) 1000 m distant.

The DOE has recently revised radiation protection standards for the public. The pertinent standards are a) 100 mrem/yr effective dose equivalent for a limited number of years of exposure, and b) 25 mrem/yr whole body dose for air pathways. The latter standard corresponds to the Environmental Protection Agency continuous exposure limit issued in 40 CFR 61, 1/85. Recent engineering design improvements to the LAMPF beam stop area have significantly reduced LAMPF's release of activation products to the atmosphere (from 31 mrem in 1984 at the nearest site boundary to approximately 11.4 mrem in 1985). The expected GTA releases will not affect LAMPF compliance with DOE 5480.1A or with 40 CFR 61.

The Laboratory environmental monitoring program monitors radiation from airborne activation products released by LAMPF. The prevailing winds are from the south and southwest. A source term for the release of all radionuclides except tritium (H-3) is obtained from ion chamber measurements that continuously sample stack flow. Thermoluminescent dosimeters (TLD) located on the downwind Laboratory boundary directly measure above-background external radiation levels to within 2 mrem/year. (Tritium is monitored separately and continuously with the release point stack.) Twelve TLD sites are located downwind at the Laboratory boundary north of LAMPF along 800 m of canyon rim. Twelve background TLD sites are about 9 km from the facility along a canyon rim near the southern boundary of the Laboratory. This background location is not influenced by any Laboratory radiation sources. The 24 TLDs are changed each calendar quarter or sooner, if LAMPF's operating schedule dictates (start-up or shut-down of the accelerator for extended periods mid-way in a calendar quarter). The radiation measurement (above background); (11.4 mrem for 1985) is obtained by subtracting the annual measurement at the background sites from the annual measurement at the Laboratory's boundary north of LAMPF.

3. <u>Effluents</u>

Waterborne effluents will consist of routine sanitary waste from restrooms at the facilities and programmed releases of slightly activated waste cooling water used to cool magnets and beam stops. Nuclides expected to be present in the GTA-1 cooling system consist mainly of water spallation products such as H-3, Be-7, C-11, N-13, and O-15. The coolant system will also contain some amount of component spallation and corrosion products. These products would be expected to contain radioactive isotopes of Co, Cu, Fe, Mn, V, Cr, and Ni. During normal system operation such products will be removed from the coolant stream and concentrated in the demineralizer beds.

TABLE II-1

GTA-1 AIR ACTIVATION PRODUCTS RELEASES

Radionuclide	Half-life	Concentration after 8 hours of operation (Ci/cm^3)	Annual Dose (mrem)
Ar-41	109.8 min	$2.48\ 10^{-6}$	$2.3\ 10^{-2}$
N-13	9.96 min	$1.55\ 10^{-7}$	$7.0\ 10^{-4}$
C-11	20.3 min	$2.59\ 10^{-8}$	$1.5\ 10^{-4}$
Cl-40	1.4 min	$2.57\ 10^{-8}$	$1.2\ 10^{-5}$
S-37	5.06 min	$2.47\ 10^{-8}$	$2.0\ 10^{-4}$
O-15	2.05 min	$1.09\ 10^{-8}$	$5.2\ 10^{-6}$
Cl-39	55.5 min	$1.02\ 10^{-8}$	$9.5\ 10^{-5}$
Cl-38	37.3 min	$4.28\ 10^{-9}$	$4.4\ 10^{-5}$
S-38	2.87 hr	$3.28\ 10^{-10}$	$5.1\ 10^{-6}$
Ar-37	35.1 days	$2.35\ 10^{-10}$	$3.4\ 10^{-9}$
C-14	5730 yr	$7.15\ 10^{-11}$	$1.9\ 10^{-8}$
O-14	1.182 min	$6.20\ 10^{-11}$	$2.4\ 10^{-8}$
H-3	12.26 yr	$3.40\ 10^{-11}$	$3.5\ 10^{-8}$
Cl-34	31 99 min	$5.24\ 10^{-11}$	$4.1\ 10^{-7}$
S-35	87.9 days	$5.75\ 10^{-12}$	$2.2\ 10^{-10}$
Ar-39	269 yr	$5.50\ 10^{-14}$	$1.5\ 10^{-9}$
Cl-36	$3.08\ 10^{5}$ yr	$4.36\ 10^{-19}$	$8.5\ 10^{-14}$

The GTA-1 cooling system will contain approximately 2500 gals. Cooling water will be drained intermittent into the TA-53 sewage system. Effluent radioactivity is not considered a hazard for the sewage system. Personnel in the Accelerator Health Protection Group (HSE-11) routinely monitor the circulating water system. When it is necessary to drain the system and dispose of the water, proper procedures will be implemented based on the level of activation. The radioactivity in the water will generally be allowed to decay to acceptable levels and then disposed of in the TA-53 lagoons. If such disposition causes concentrations in the lagoons to exceed DOE regulations, the water will be removed to the Laboratory radioactive liquid waste facility at TA-50 and disposed of there. In past years radioactivity in effluents released from the TA-53 lagoons was reported annually to the DOE and the Environmental Protection Agency. Aerators have been added to the two original lagoon cells and a third cell was added in 1985. Since then no liquid effluent has been discharged from these lagoons and none is expected to be in the future.

4. Soil Activation

The beam stops cause negligible soil activation. Consequently, nuclide migration from the GTA site is not likely. The beam stops are located near the centers of the buildings and are thus not subject to direct exposure from rain water. Surface water drainage paths do not lead under the proposed buildings, and ground water is approximately 900 feet below the site elevation. There is no known mechanism for transporting nuclides from the beam stop area to the ground water.

5. Electrical

Electrical hazards are present in the injector power supply, the radio frequency (rf) power system, and the beam sensing laser power supply. In all cases access to high voltage component containers or enclosures is interlocked so that startup is prevented or the system shutdown if the interlock is violated. Maintenance of high voltage systems is performed under SOPs that have been reviewed by operation supervisors and the Laboratory's HSE Division.

6. RF Radiation

The rf power that drives the RFQ and DTL accelerating sections is completely enclosed. RF power detectors monitor areas where rf subsystems are located and give an alarm if present levels are exceeded.

7. Laser Radiation

Laser beams are part of the H° beam sensing scheme. The laser beams are capable of causing severe eye damage and skin burns. Protective measures include training of personnel in operation and maintenance, local shields and enclosures interlocks, personnel exclusion areas, safety eyewear and the use of SOPs.

8. Fire

The principle sources of flammable materials and fire protection are discussed below.

Dielectric Oil

Dielectric oil is used in several high voltage components. The largest quantities are in the rf power system. Capacitor banks will use capacitors filled with either General Electric's "Geconal" or HATCO Chemical's HATCOL 101. Both are phthalate esters with a flash point of 420°F. The rf power supply will be part of a bid package going to commercial vendors. The type of oil used in those components is not known but will be required to have a flash point greater than 293°F no oil will contain any PCBs. All indoor areas housing large, oil-filled components will be covered by the fire sprinkler system.

Laser Dye Solvent

The laser used in the H° beam sensing system will probably employ a dye dissolved in an as yet unspecified organic solvent. The volume of the solvent is expected to be less than three gallons and will be contained in a sealed, recirculating system. The laser area is covered by the fire sprinkler system.

Cables

There will be a large number of elastomer-covered cables throughout the facility. Cable runs will be in conduit trays and trenches. The areas having cable runs will be covered by the fire sprinkler system.

Fire Protection

The new addition, the accelerator vault and the west low bay area beneath the new drop ceiling will comprise six zones to be added to the existing sprinkler system. The fire protection contractor will be responsible for performing hydraulic calculations and producing drawings that meet the provisions of NFPA 13.

The accelerator vault zone will be protected by a dry pipe sprinkler system. The other additional zones will be protected by an ordinary hazard, Class II, wet pipe sprinkler system.

Firefighting for the site is provided by the Los Alamos Fire Department. Under ideal conditions fire apparatus and ambulances from the nearest fire station can reach the site in five minutes. Weather, road conditions and traffic may increase that time. Two fire companies and a rescue truck will respond to an alarm.

9. Explosion

The possibility of explosion during cryopump regeneration exists. Only a small fraction of hydrogen used fed to the injector is converted to H^- particles. The remainder expands into the vacuum envelope and is taken out by cryopumps. Oxygen also condenses in the cryopumps. It is conceivable that during pump regeneration an explosive hydrogen-oxygen mixture could be produced. The prevention of such an explosion is to eliminate any ignition sources, for example conization vacuum gauges, before regeneration begins.

B. Hazardous Operations and Energy Sources

1. Ionizing Radiation Hazards

The hazards arising from operations are similar from the start of initial testing through routine operation of the facility. They are primarily the hazards of exposure to ionizing radiation and electric shock. When the beam is on, stray parts of the beam can strike the accelerator structure and result in ionizing radiation. The accelerator vault is an exclusion area when the beam is on.

A second ionizing radiation hazard is the beam stops. All the beam energy is dissipated in one or the other of the beam stops and they become activated. Normally they require no attention. Maintenance can be performed remotely when required.

Maintenance and adjustment of accelerator components will be possible after a sufficient radiation decay period.

GTA-1 operations will be under the direct and continuous surveillance of group HSE-11, Accelerator Health Protection.

2. Electric Shock Hazards

Accelerator operation requires the functioning of several high voltage power supplies. Approximate power supply voltages are listed below.

Injector	100 kV
RF Power	110 kV
Laser System	10 kV

Access to all uninsulated high voltage components is interlocked so that power to the components is turned off if the interlock is violated. Maintenance of high voltage systems is by trained personnel and in accordance with written and approved SOPs

3. Energy Sources

The energy sources associated with GTA-1 are discussed below.

Accelerated Particle Beam

The energy source in the facility most likely to be hazardous or to cause damage is the accelerated beam. It has an average power of 5.0 kW and a peak power of 5.0 MW. Under normal conditions some of the accelerated particles strike structures and shielding and generate the ionizing radiation described elsewhere in this analysis. Possible malfunctions of the accelerator system could result in the full beam's striking vacuum walls or other structures and damaging or destroying them. The accident would also generate ionizing radiation at an unexpected point.

Natural Gas

Natural Gas is used only for space heating. Gas furnaces satisfy the provisions of NFPA No. 54, National Fuel Gas Code.

Electrical Power

The rf power system is the largest user of electrical power. The installed electrical supply to the facility is approximately 10 MW at 13.2 kV.

Organic Dye Solvent

The beam sensing laser system may employ a dye laser. Dye will be dissolved in an organic liquid, possibly ethanol. The volume of the solvent will be less than three gallons.

Dielectric Oil

Dielectric oil will be contained in many of the high voltage components. Flash points will range from 293°F to 425°F. Quantities will not be known until completion of rf power system design. The six modulator tanks will have a combined volume of approximately 8,000 gallons

Rotating Equipment

The largest pieces of rotating equipment are conventional HVAC items.

C. Numbers of Employees Exposed to Hazards

1. Assumed Risks

The number of employees exposed to the various hazards depends largely on the activity in progress. There will be a minimum accelerator operating crew plus those persons involved with the test at hand. Additional people are required to perform experiments with the magnetic optics, the neutralizer or the beam sensing system. The maximum number of employees that might be expected to be present during operation is an accelerator crew of 4 plus 6 persons for a particular component test.

2. Imposed Risk

There might be 20 employees within a radius of 100 feet of GTA-1 who might be exposed to ionizing radiation during a ground release of activated air. The dose is estimated to be 8 mrem.

D. Offsite Concerns

The only offsite concern is that of public exposure to airborne radioactivity from exhausting accelerator vault air. That concern is discussed in sections II. A. 2. and IV. C. 1.

III. Safety Systems

A. Engineered Safety Systems

1. Radiation Personnel Safety System

The radiation personnel safety system primarily controls access to the accelerator vault. There are three features of the system: 1) scram buttons located in the accelerator vault on the east wall, west wall, center section and H° beam stop, 2) a sweep sequence of the vault area prior to startup, and 3) a kirk-key system for controlling access to the vault.

Pushing a scram button immediately shuts down the accelerator. The button remains in its scrammed state and restart requires that the sweep sequence be performed.

The sweep system has push buttons installed on the east, west, north and south walls of the accelerator vault. Each button must be activated during the search for persons in the vault. After the four push buttons have been activated, push buttons at each of the three entrance doors are activated. Following activation of the third push button the sweep person has 20 seconds to leave the vault by any door. He must leave in 20 seconds or opening a door will disable the system. He has the master kirk-key which permits startup.

When all scram buttons and sweep push buttons are properly configured and the key returned to the control room, the machine may be started. The first action in the startup is 60 second sounding of the alarm horn. Following the horn sounding, high voltage may be turned on and the accelerator subsystems energized.

To enter the vault after running, the master kirk-key is removed from the console (which would shutdown the accelerator if it were running). The master key can be inserted in a transfer box which traps the master and releases keys to doors. The reverse must happen to release the master key for inserting in the startup circuit lock.

All vault doors have crash hardware on the vault side and cannot be locked preventing exit from the vault.

2. Accelerator Vault Access

The accelerator vault and beam stop areas will be closed to all personnel during beam-on. Pedestrian traffic during beam-off operation will be through shield block labyrinths with kirk-key interlocked doors from the accelerator vault. A sweep of the accelerator vault will be made prior to enabling accelerator startup.

3. Radiation Monitoring

The stack exhaust will be monitored continuously and the accelerator vault and occupied areas adjacent to the vault will be monitored as operations dictate. The monitoring for radioactive air will be done using 50 liter Kanne ion chambers and appropriate electrometer units. These units will have local readouts and remote readouts at the console in the control room.

Neutrons in occupied areas will be monitored with Albatross IV pulsed neutron monitors which, again, will have local and remote readout capabilities.

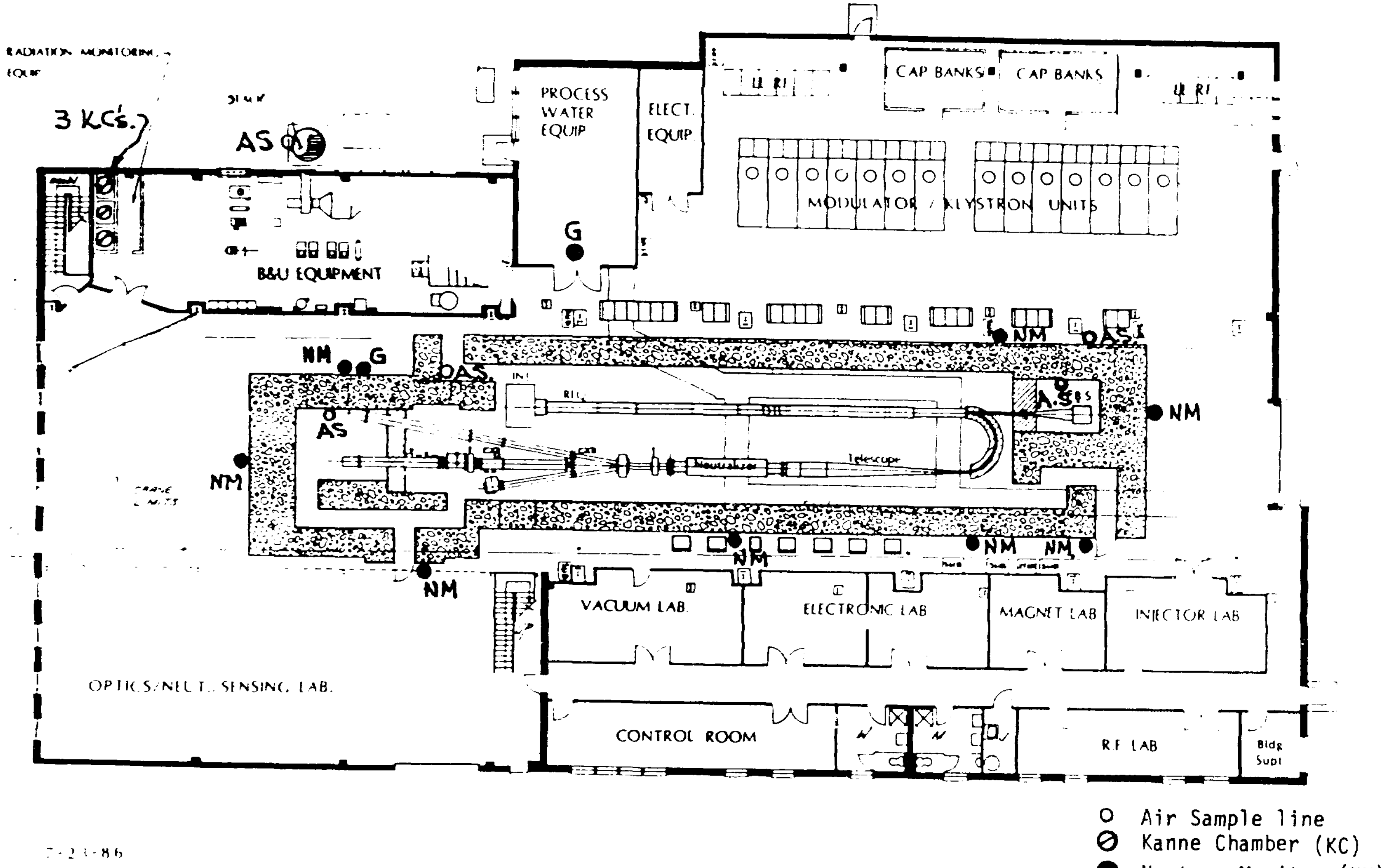
Gamma radiation in selected locations (e.g., the contaminated water room) will be monitored with in place detectors having remote readout capabilities. This monitoring will be supplemented by the use of hand held portable instrument surveys. Figure III-1 shows location of radiation monitors.

4. Beam Spill Monitoring

Beam spill (the beam striking any accelerator components) can result in severe damage to a component in a very short time. Beam spill is detected by radiation, vacuum and beam position monitors and, depending on the indication from a monitor, the beam will be positioned properly or shut off. A monitor trip alerts control room personnel. Control is fast enough to shut off the beam for a fraction of a pulse and turn it on for the next pulse. GTA-1 has some 15 independent monitors. Since no personnel are in the vault when the beam is on, this monitoring system is primarily for the protection of equipment.

5. High Voltage Interlocks

The high voltage power supplies of the injector and rf system are enclosed and the access doors interlocked. The supplies cannot be energized when access doors are opened and, after energizing, opening a door deenergizes and dumps the stored energy from the capacitor banks. Surveillance of the condition of access door interlocks is maintained in the control room. The interlocks are part of the run permit system.



GTA-1 Radiation Monitor Locations
FIGURE III-1

6. RF Personnel Safety System

The rf personnel safety system is an emergency shutdown system. It consists of a push button station near the rf high voltage power supply that deenergizes the rf power system..

7. Scram System

Scram buttons are installed at appropriate locations in the facility. Pushing a button immediately shuts down the machine and sounds an alarm in the control room. The system is primarily a safety feature for a person accidentally remaining in the accelerator vault when the accelerator is started up.

8. Ventilation System

The ventilation system for the accelerator vault is turned off during operations so that no radioactive air is discharged to the atmosphere during accelerator operation. The air remains stagnant unless personnel entry is required, in which case air exhausting is begun and continued until personnel leave the area. Access is permitted only after radiation levels are monitored and determined to be at a permissible entry level.

In the event of a fire, exhaust fans are turned on automatically to clear smoke as an aid to fire fighters.

8. Emergency Power

If the electrical power system fails, the following systems will have emergency power and will remain operative.

1. Radiation monitors
2. Telephone
3. Building power emergency shutdown
4. Mechanical equipment control console
5. Selected computer data equipment

Safety interlocks fail-safe when power is interrupted.

B. Management or Administration Controls

Film Badges

All personnel working in the facility are included in the Laboratory's dosimetry program. Visitors to the facility will be issued dosimeters if they enter radiation areas.

Crane Inspection

The accelerator vault crane and associated slings and other lifting hardware will be marketed to show load limit and be inspected in accordance with ANSI and DOE requirements.

C. Safety-Related Documentation

Environmental Assessment

Environmental Assessment, DOE EA-304, was prepared for GTA-1 and GTA-2. The document was approved by ALO, April 1986.

Radiation and Shielding Calculations

Documents concerned with radiation and shielding calculation are listed below. Copies of those memos constitute the Appendix.

1. Letter, R. J. Morford to Theodore R. Cole, Subject: ATSU, Linac Air Activation, date received April 12, 1985

2. Memorandum, Jean Dewart and Tom Buhl to Colleen Olinger, Subject: Routine Releases from the Accelerator Test Stand Upgrade, dated July 25, 1985

3. Letter, R. J. Morford to Theodore R. Cole, Subject: ATSU, Waveguide Penetration, dated January 20, 1986.

4. Letter, R. J. Morford to Theodore R. Cole, Subject: GTA-1 Bulk Shielding, dated January 27, 1986.

5. Letter, R. J. Morford to Theodore R. Cole, Subject: GTA-1, Coaxial Penetrations, dated March 10, 1986.

Standard Operating Procedures (SOPs)

The Laboratory requires that all potentially hazardous, routine operations be covered by SOPs. GTA-1 SOPs are generated by the technical personnel involved and approved by the AT-Division Leader and by appropriate AT Division Group Leaders. They are reviewed by HSE-Division and ENG Divisions who recommend any changes believed necessary. Line organization leaders are directly responsible for safety and health.

Special Work Permits

Nonroutine work in hazardous areas or with hazardous materials is done in accordance with special work permits that are approved in advance of the work by HSE and ENG AT Divisions as required.

Experimental Test Plans

Experimental test objectives and procedures are contained in experimental test plans. Such plans are used primarily for programmatic objectives but safety and health considerations are included.

IV. Safety Systems Failures

A. Materials at Risk and Energy Sources

Accelerator Structure

The accelerator structure is at risk if the accelerated particle beam wanders from its proper path. The beam is sufficiently powerful to melt the vacuum envelope or other structures if it strikes them and beam-monitoring safety devices do not shutdown the system.

Portions of the Building

In the event of dielectric oil fire a substantial portion of the building could be severely damaged if the water sprinkler system were inoperative or ineffective. The probability that more than one of the 1400 gallon oil-filled modulator tanks would be involved in a fire is slight.

B. Credible Challenges to Safety Systems

1. Normal Conditions

Safe Working Conditions

The hazards that must be controlled under normal operating conditions are ionizing radiation, high voltage, and laser radiation.

Control of Radioactive Material Release

To control the release of radioactive materials to the environment activated air in the accelerator vault is stagnant during operation. It is normally exhausted to atmosphere immediately following operations each day.

2. Abnormal Conditions

The hazards that must be controlled as a result of credible accidents are the same as for normal operating conditions plus the hazards associated with a dielectric oil spill. The most severe credible accident in the facility is an oil fire.

C. Consequence of Failures of Safety Systems

1. Normal Conditions

Accelerator Vault Access Interlock

Failure of the accelerator vault interlock would permit an individual to enter the vault during beam-on operations. Radiation levels at some locations in the vault might be as high as _____ r/hr. Not only must the door interlock malfunction, the flashing warning light must be off.

Radiation Monitoring

Failure of one or more of the radiation monitoring systems could result in an individual receiving a low radiation dose. Radiation monitors are located in areas in which radiation levels are normally well below those permissible. Some other circumstance is necessary for levels in monitored areas to be higher than permissible

Beam Spill Monitoring

Failure of one of the fifteen beam spill monitors will not disable beam spill control. Failure of all beam spill monitors could result in the beam's melting the vacuum envelope and close in accelerator structure.

High Voltage Interlocks

Failure of a high voltage interlock could result exposure of personnel to lethal high voltage only if the DOP required use of grounding were not followed.

Scram System

Failure of the scram or alarm system at a time when a person was in the accelerator vault and the accelerator beam was brought up could result in a high radiation dose to that person. For this accident to happen, the person involved would have to remain in the area even though the horn had sounded. Exit from the area is always possible and shuts down the accelerator.

Ventilation System

If the ventilation system should be turned on during beam-on operations, activated air products could be exhausted from the stack with little decay time. Assuming the malfunction went undetected for a full operating period, the dose to a member of the public would be increased by approximately .09 mrem.

Water Sprinkler System

The water sprinkler system is required to be in service under normal conditions.

2. Abnormal Conditions

Accelerator Vault Access Interlocks

There are no abnormal conditions that would increase the hazard of accelerator vault access interlock failure over that described under normal conditions.

Radiation Monitors

For the failure of radiation monitors to be hazardous the failure would have to accompany some other failure. Monitors outside the accelerator vault are in a low level radiation field and their failure would not result in an appreciable dose to anyone unless the vault block seals leaked at the same time when vault pressure was higher than outside pressure and the vault air was radioactive.

Failure of air sampling in the vault might indicate that entrance was permitted, but no one is permitted to enter until the radiation level within is independently measured by a HSE-11 monitor.

Failure of the gamma monitor in the contaminated water equipment room would result in no hazard unless the SOP requiring an independent HSE-11 survey were disregarded.

Beam Spill Monitoring

There are no abnormal conditions that could increase the hazard of beam spill monitoring failure over that described for normal operating conditions.

High Voltage Interlocks

If a high voltage interlock failed and an individual failed to use grounding hooks as specified by the SOP, a severe electrical shock could occur.

Scram System

The manually-operated scram system is provided primarily for use by personnel who might be in the accelerator vault when the beam-on operations begin. The system also permits manual shutdown of operations for any reason and supplements automatic shutdown systems. No abnormal condition has been postulated that the loss of this supplemental shutdown capability increases the hazard over that described for normal operations.

Ventilation System

In the event of a fire in the facility, the ventilation system automatically exhausts smoke from a ventilation zone. Failure of the system to perform that function would make firefighting much more difficult.

Fire Sprinkler System

Failure of the fire sprinkler system when a facility fire has started could permit spread of the fire and, if there were no fire department response, could result in complete loss of the facility.

D. Interactions with Nearby Facilities

1. Normal Conditions

There is no interaction with nearby facilities during normal conditions.

2. Abnormal Conditions

Ground Release of Activated Air

The ground release of activated air could result in an 8 mrem radiation dose to an individual who was 100 m downwind.

Release of Activated Cooling Water

Accidentally released slightly activated cooling water could drain outside the facility and put nearby personnel at risk to radioactive contamination. The radiation dose would almost certainly be less than that permitted by ______________________________.

E. Potential for Program Interrruption

The most serious credible accident is that of a major fire in the facility. Such a fire would be critical and delay GTA-1 development by one year which, in turn, would delay completion of GTA-2 which uses GTA-1 as a front end. The ISE-1 flight experiment is contingent on maintaining the GTA schedules. The partial loss of the GTA-1 facility would have a serious impact on the Laboratory's, and the nation's neutral particle beam program.

F. Estimate of Offsite Consequences

1. Normal Operations

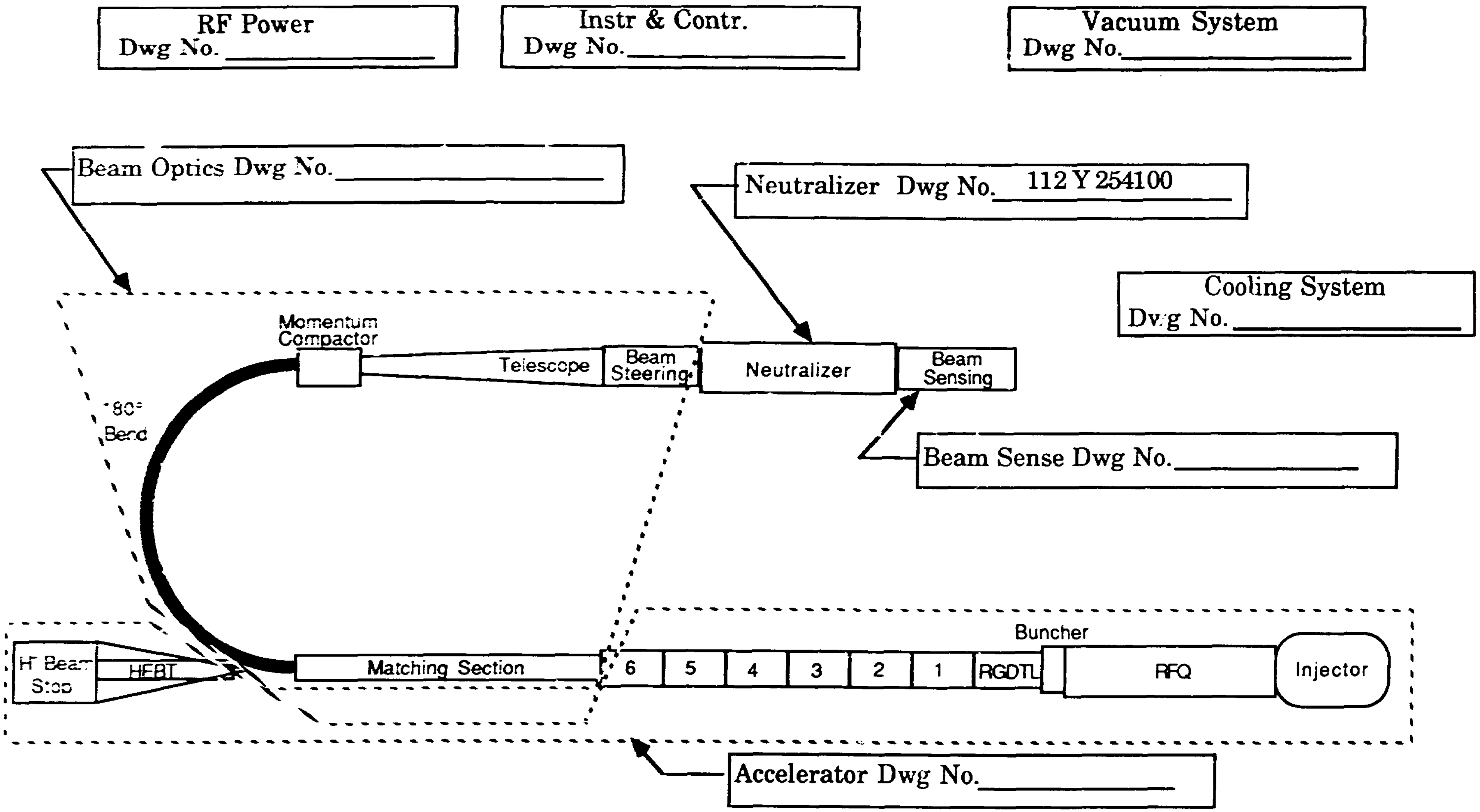
The only offsite consequences from normal operations is the conceivable exposure of the public 1000 m from the facility to airborne radiation from the routine venting radioactive isotopes from the accelerator vault. The calculated dose is .03 mrem per year.

2. Abnormal Conditions

An accidental unscheduled release of airborne radioactive isotopes could result in a one-time dose to the public at 1000 m of .08 mrem.

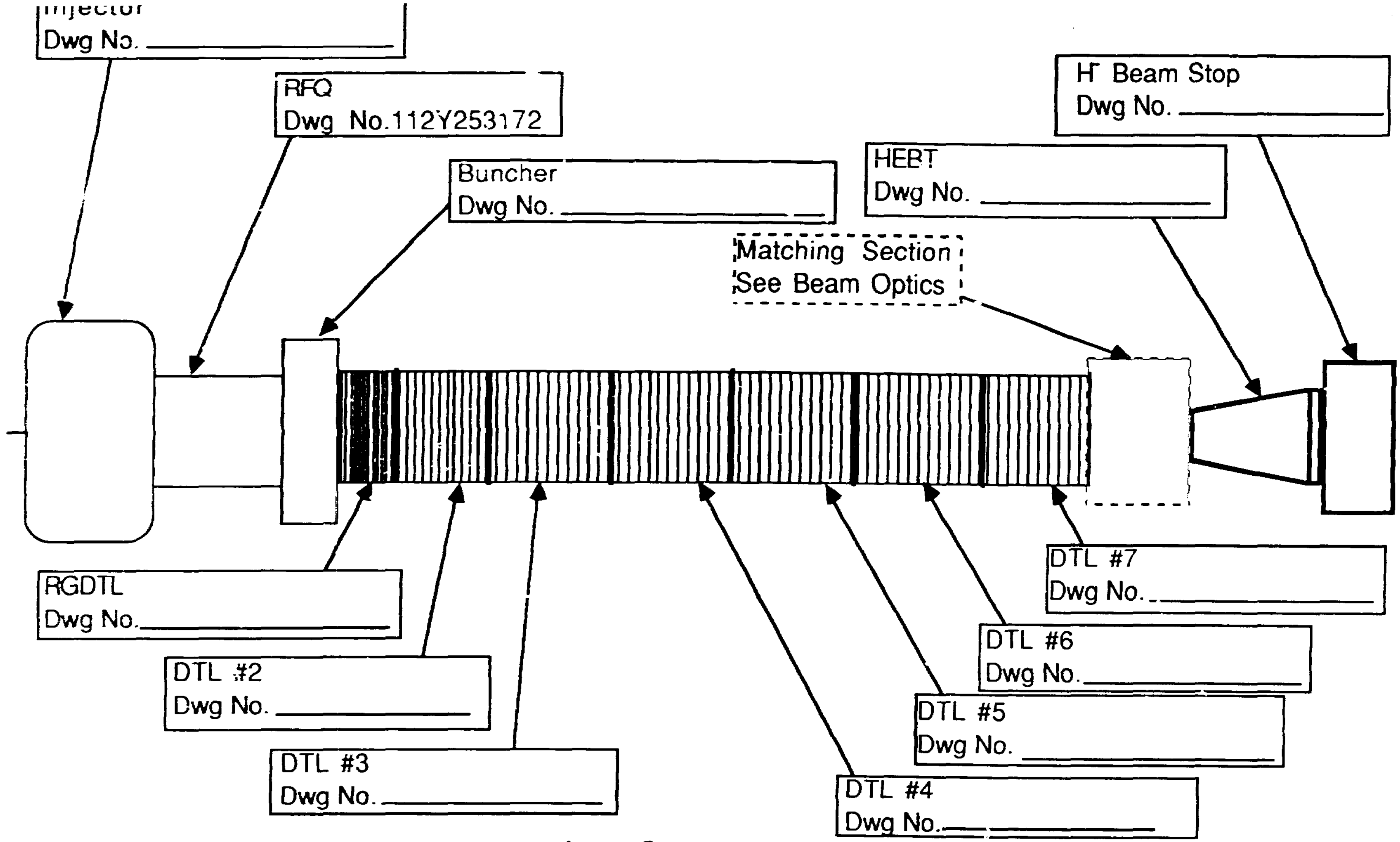
Appendix 'C'

System Assembly Drawings

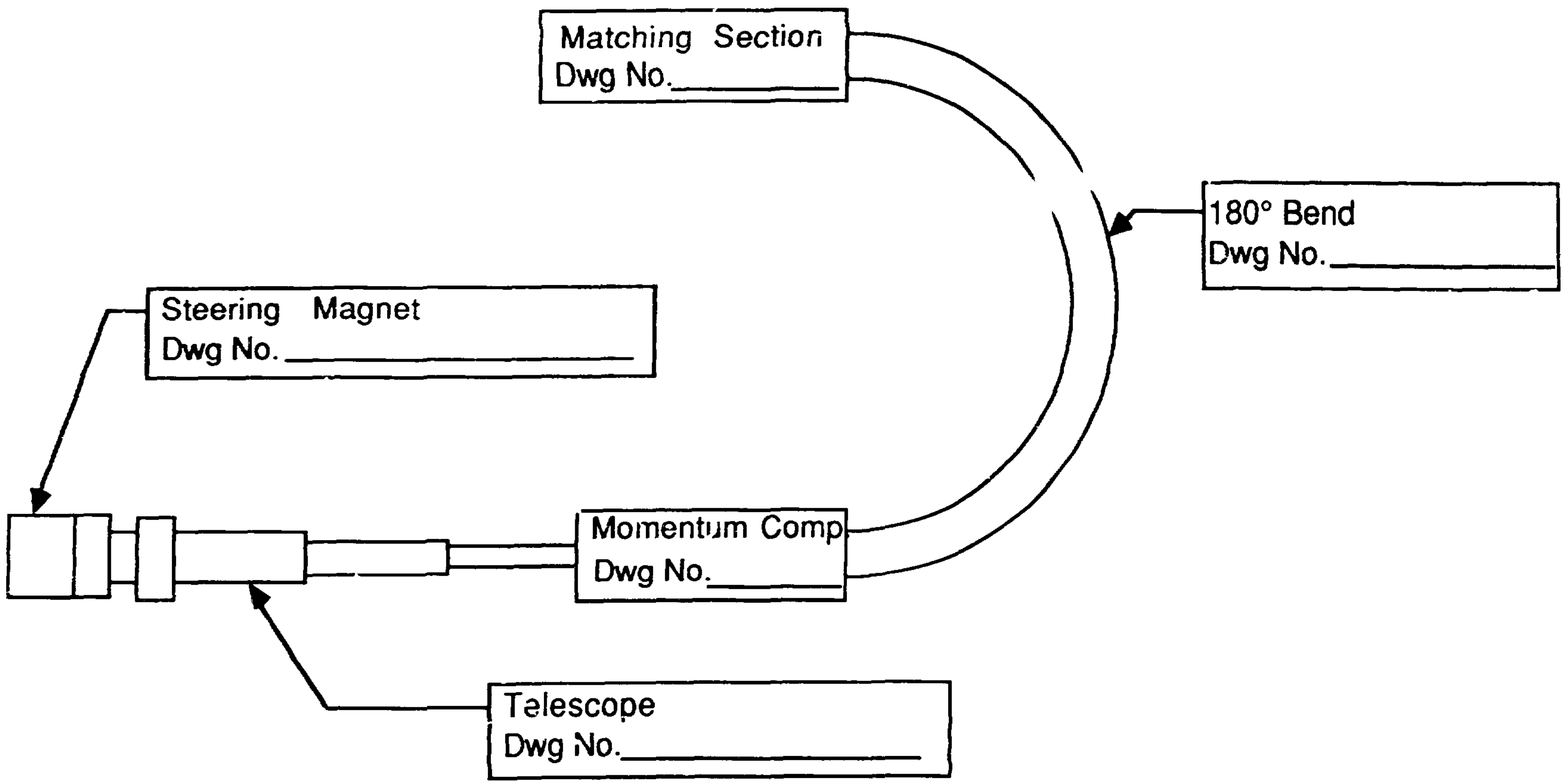


System Assembly Drawing Numbers

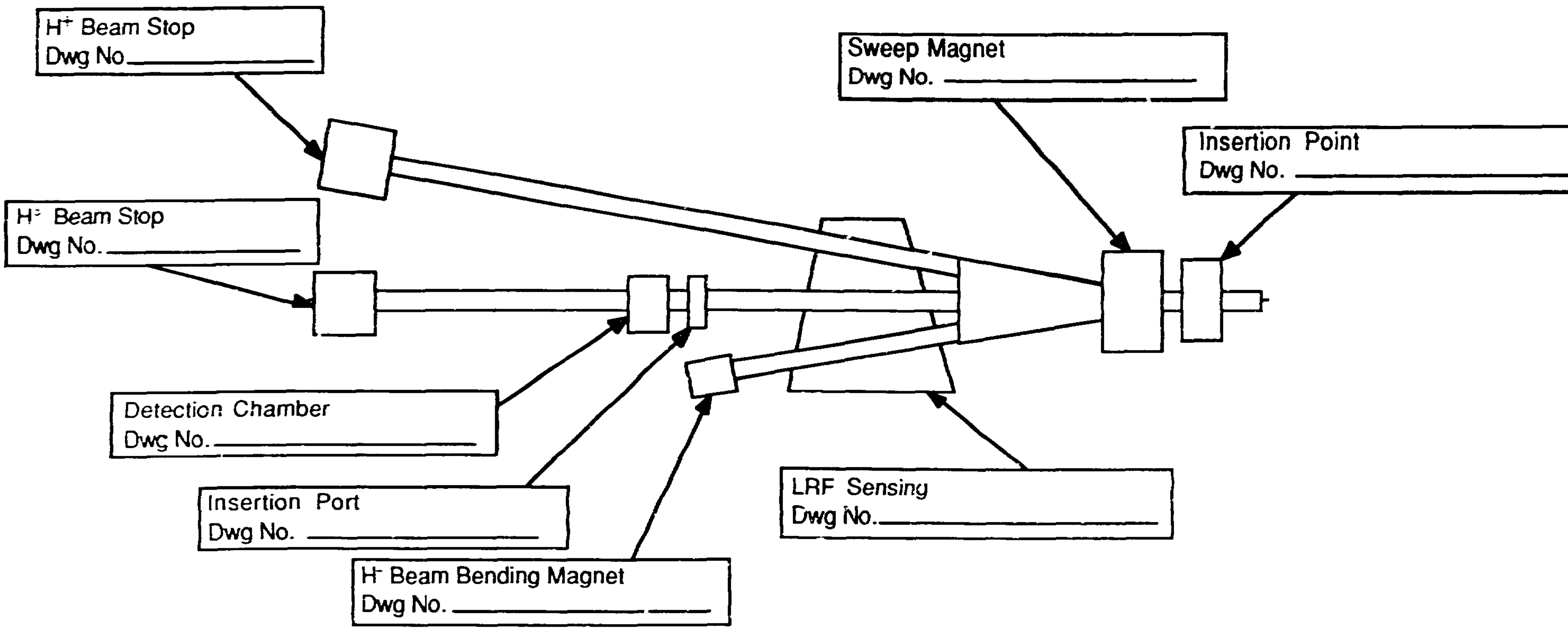
GTA Phase 1



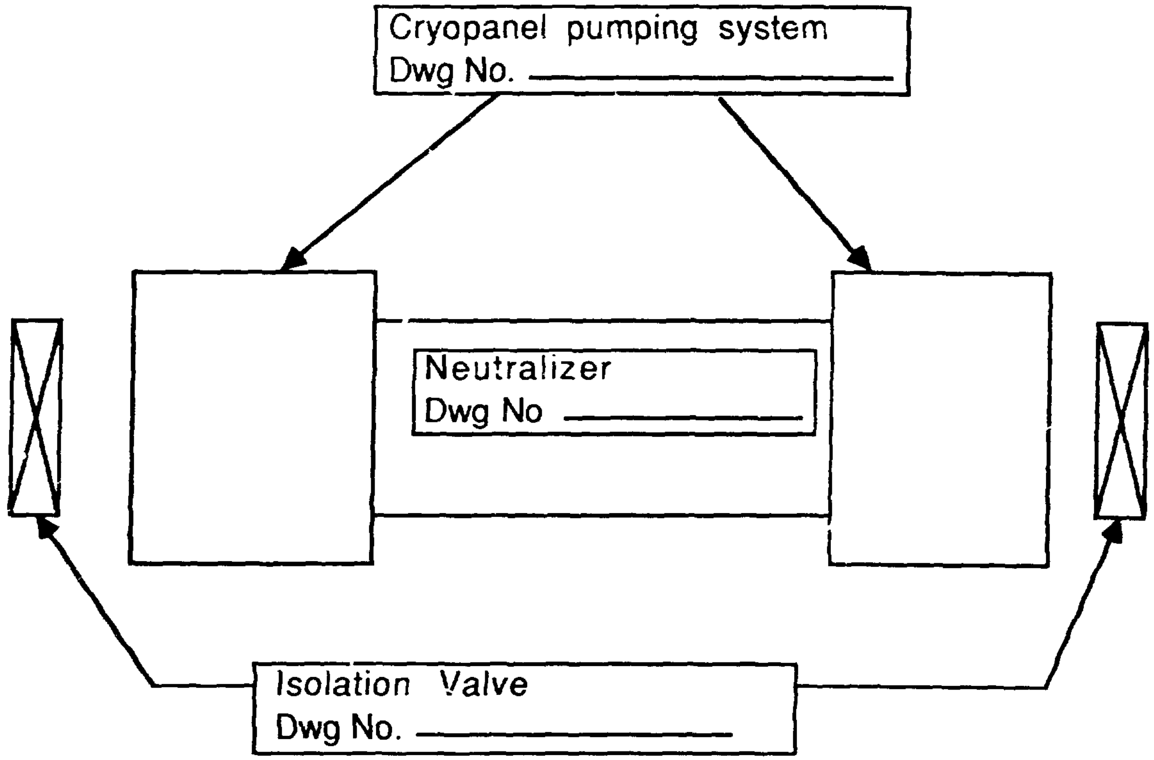
Accelerator Sub-Assembly Drawing Numbers



Beam Magnetic Optics
Sub-Assembly
Drawing Numbers



Beam Sensing
Sub-Assembly Drawing Numbers



Neutralizer
Sub-Assembly
Drawing Numbers

APPENDIX D

GTA

Drawing

Tree

112Y254000

11 Aug 1986

Revision 1

GTA LOS ALAMOS

LOS ALAMOS NATIONAL LABORATORY

LOS ALAMOS, NEW MEXICO 87545

112Y254000 -	System Drawing Tree	
112Y254001	- Specification Tree	**Page 3**
112Y254002	- Interface Tree	
112Y____	- Accelerator System	
112Y253145	-Injector	**Page 10**
112Y25___	-DTL Assembly	**Page 9**
112Y25____	-RFQ Assembly	
112Y___	- Beam Sense System	
112Y___	- Instr. & Control System	
112Y___	- Facilities	
112Y___	- Neutralizer System	
112Y___	- Beam Optics System	
112Y___	- RF Power System	

GTA LOS ALAMOS

LOS ALAMOS NATIONAL LABORATORY

LOS ALAMOS, NEW MEXICO 87545

112Y254006 - Accelerator System Specification

112Y254007 - GTA-1 Injector Specification

112Y254008 - GTA-1 RFQ Specification

112Y254009 - RG DTL Specification

112Y254010 - 50 Mev DTL Specification

112Y254011 - GTA-1 Beam Stop Specification

112Y254012 - GTA-2 100 Mev DTL Specification

112Y254013 - GTA-2 Beam Stop Specification

GTA LOS ALAMOS

LOS ALAMOS NATIONAL LABORATORY

LOS ALAMOS, NEW MEXICO 87545

112Y254014 - Beam Magnetic Optics System Specification

112Y254015 - GTA-1 Matching Section Specification

112Y254016 - GTA-1 180° Bend Specification

112Y254017 - GTA-1 Beam Expansion Telescope Specification

112Y254018 - GTA-1 Steering Magnet Specification

112Y254019 - GTA-1 Magnet Material Specification

112Y254020 - GTA-1 Magnet Mapping Equip. Specification

112Y254045 - Fixed Field Quadrupole Triplet Specification

112Y254047 - Fixed Field Quadrupole Eyepiece Specification

112Y254023 - Beam Sensing System Specification

112Y254024 - GTA-1 Mech Scoring System Specification

112Y254025 - GTA-1 LRF System Specification

112Y254026 - GTA-1 Doppler Sense System Specification

112Y254027 - GTA-1 Beam Stop System Specification

112Y254029 - RF Power System Specification

112Y254030 - Power Conditioning System Specification

112Y254048 - Klystron Specification

112Y254032 - Waveguide Specification

112Y254033 - Low Level RF Specification

112Y254034 - EM Compatibility Specification

112Y254035 - Control Console Specification

112Y254044 - GTA-2 Hi Voltage Capacitor Specification

112Y254046 - Klystron Modulator Specification

112Y254251 - GTA-1 RF Power Supply Specification

112Y254036 - Facilities System Specification

- 112Y254037 - GTA-1 Facilities Specification
  - 112Y254038 - GTA-1 Building Specification
  - 112Y254040 - GTA-2 Facilities Shielding Specification
  - 112Y254041 - GTA-2 Building Specification
  - 112Y254042 - GTA-2 Shielding Specification
  - 112Y254043 - Tech Support Bldg Specification
  - 112Y254049 - GTA-1 Shielding Specification

112Y253____ - DTL Assembly

- 112Y253067 - RG DTL Physics I'face
- 112Y253092 - RG DTL Mech I'face
- 112Y253071 - RG DTL Tank Assy
  - 112Y253079 - RG DTL Girder Assy
    - 112Y253095 - Girder
  - 112Y253083 - Girder/Hatch RF Seal
  - 112Y253084 - Girder/Hatch 'O' Ring
  - 112Y253078 - Post Coupler
  - 112Y253068 - RF Drive Loop
  - 112Y253093 - Slug Tuner
  - 112Y253097 - Tank Hatch & Endwalls
  - 112Y253094 - Drift Tube
- 112Y253164 - DTL Tank Assy Dwg Tree

112Y253145 Injector Assy Tree
- 112Y253205 Physics Interface
- 112Y253206 Mechanical Interface
- 112Y253166 Instr & Control
  - 112Y25____ High Voltage System
    - 112Y253211 High Voltage Block Diag.
    - 112Y25____ Mechanical Details
    - 112Y25____ Dome Schematic
    - 112Y25____ P. S. Schematic
  - 112Y253143 Injector Assembly
    - 112Y253158 Source Assembly
      - 112Y253159 Anode Assembly
      - 112Y253160 Cathode Assembly
      - 112Y253161 Arc Region Housing
    - 112Y253253 Source Installation
      - 112Y253202 Cesium Oven
      - 112Y253201 Gas Puff Valve
    - 112Y25____ Extractor
      - 112Y25____ Insulator
    - 112Y253203 Column Assembly
    - 112Y25____ LEBT Assembly
      - 94Y222603 Mini Scanner
      - 94Y222631 Faraday Cup
      - 112Y253210 Diagnostic Mountings
      - 112Y253207 Vacuum Box
      - 112Y25____ RFQ I'fce iso valve
      - 112Y25____ Quad Hsng inside column
      - 112Y253188 1" Quad Assembly
      - 112Y253189 2" Quad Assembly
      - 112Y25____ Quad Translator Asseembly
      - 112Y25____ Quad Rotator Assembly
      - 112Y25____ Quad Support
    - 112Y253199 Dome Assembly
      - 112Y25____ Support Stand
    - 112Y25____ External Equipment

APPENDIX E. SUBSYSTEM CONCEPTUAL DESIGN REVIEW QUESTIONS AND ANSWERS

GTA ION INJECTOR CONCEPTUAL DESIGN REVIEW COMMENTS AND ANSWERS

1. What are the drawing numbers for the injector and how can copies be obtained?

The drawing tree for the injector is nearly ready for release. The drawing number for the drawing tree is 112Y-253145. It will be placed under configuration control following the preliminary design review.

At the present time several of the drawings have been released for fabrication. A number of the drawings in the injector package show a great deal of detail; however, most of those drawings are considered to be in the conceptual stage. Drawings in the conceptual stage can be released but must be clearly marked "Conceptual Design Only Not For Fabrication." Requests for conceptual-stage drawings should be made through W. Reichelt in the GTA Program Office. We need to develop the details for an orderly process for getting drawings to those who need them.

Dome Biasing

Considerable discussion ensued during the Design Review and was centered on the method for developing the 100-kV acceleration voltage for the beam. For an H^- ion injector, the ion source must be biased a total of 100 kV below the electrical potential of the rest of the accelerator in order to bring the ions up to the correct velocity for injection into the RFQ. This bias voltage is termed the "Dome Voltage."

The following four questions are grouped into a single question because the response is the result of a tradeoff study.

2. Why pulse the dome voltage? Is pulsing unnecessarily complex? Does pulsing by itself yield a low duty factor? What are the tradeoffs in reliability from pulsing?

There are three general methods for supplying the 100 kV necessary for acceleration of the beam.

First, a capacitor can be continuously charged with a small current capacity power supply, and the source can be pulsed to the desired voltage by a series regulator tube that supplies the required constant voltage at the required time. In this mode there is no droop of the voltage until the capacitator is bled below the regulated voltage or the duty cycle becomes too great for the power supply to maintain the charge on the capacitator.

Second, the same technique may be applied as in first case but the 100 kV is applied to the electrode at all times. Current would be drawn from the capacitator only when the ion beam was being extracted or when some other emission source was present.

Third, a well-regulated power supply with enough current capacity to continuously supply the required beam and loss current (500 mA at 100 kV) would be provided.

There is little difference between the first and second methods. The pulse regulation techniques have been used on ATS and are planned for the BEAR system. We, in collaboration with P. Allison and R. Stevens of AT-2, have made some modifications to the currently implemented systems that result in some decrease in the existing complexity and that should result in a small improvement in operation. The equipment, which has been ordered, will allow operation to a maximum duty factor of nearly 1% with the addition of (at most) an extra capacitator although we are rating the system at 0.1% df.

Pulsed modulation of the dome voltage is important from the standpoint of system reliability. The probability of a breakdown is proportional to the time that the system is maintained at high voltage. The probability of breakdown or unwanted electron emission is enhanced with the cesiated ion sources due to the presence of cesium on the various surfaces (insulators and electrodes) of the injector, which will build up as the result of operation.

In the second case the series regulator tube is not turned on and off, but the same complexity of regulation would be required to maintain the voltage constant as the beam developed at extraction time. This case has the disadvantage that since voltage is applied at all times, the probability of arc-over would be greater than in the first case. The electron current being drawn during the beam-off period would require that the reserve capacity of the power supply be larger if the system was to be operated near the duty cycle limits. There would only be minor differences in the design of the first and second types of systems.

The third method, while conceptually simple, is the most difficult in terms of obtaining a power source with the required level of regulation, and it does not lend itself to the requirements of the ISE missions. Such a supply would be at least an order of magnitude larger in both weight and volume and would represent a larger current drain on the system. In addition, this system would be subject to time enhancement of the probability of breakdown.

<u>Action Items Slice</u> - Complete regulator design to preliminary design point and release drawings.

3. Pulsing the dome may add considerable EMI especially in the displacement current to charge the dome.

The present design of the dome will have a capacitance of about 900 pF as compared to the capacitance of the isolation transformer of about pF. There will be some radiated energy from the system. Control of the radiation by proper shielding and careful design of the system will be necessary. Single point grounding of the entire injector package will be necessary since the ground potential will be driven by the rf from the rest of the system. Remote location of the dome electronics package will make computer control, especially automatic control, nearly impossible.

4. Pulsing of the accelerator column adds weigh, heat to the dome, and avoids the HV question at higher duty factors.

As was described in the answer to the question about the technique of generating the high voltage, there is little weight difference between the series regulated pulsed and series regulated continuous supplies. A full capacity dc supply, on the other hand, would weigh at least one and possibly nearly two orders of magnitude more than a series regulated supply and occupy several times the volume.

The present plan is to locate the 100 kV supply outside of the dome so that it would generate little or no heating of the dome.

The pulsed series regulation technique does not avoid the issue of larger duty factors. By parallel operation of existing off-the-shelf power supplies, increasing the storage capacitance, and using a regulation tube with a larger current rating, the 5% duty factor can be reached.

5. Would anything be gained by making the dome voltage pulse wider?

The width or the dome voltage pulse is determined by the operating conditions of the source necessary to achieve the required output. The entire source could be run at a longer pulse length at the cost of a reduced lifetime of the source and, consequently, a lower reliability of the system. The object is to run the source and the injector for as short a time as possible, consistent with meeting the required ion output. The optimum pulse lengths must be determined experimentally, although the experience gained from operation of the BEAR injector will serve as a useful guide.

6. It may be difficult to obtain voltage regulation of 0.1%. Is this degree of voltage regulation necessary?

We feel that 0.1% regulation of the acceleration, extractor, and focus voltages is achievable. The GTA requirements document (in its various implementations) has listed 0.1% regulation as the design goal for some time. The issue was raised as to whether that degree of voltage control in the injector is necessary for good operation of the rest of the system. I will have to defer to the beam dynamics people for the answer to that question.

7. What will the physical size and access of the dome be?

The dimensions of the dome are now in the early stages of definition. The initial conceptual sketch of the dome, which is based on the known and estimated needs of I&C, power and diagnostics, leads to a dome with dimensions of 7' x 7' x 5' including the grounded protective cover. This size, while small by the past dome design experience, is too large from the standpoint of a flight unit. A considerable reduction of the volume of the components would be possible if all of the internal electronics packages were redesigned with packaging as a major design constraint. The GTA dome must contain some space for additional diagnostic equipment, which is not now envisioned. The design for the dome is now under active consideration and it will evolve rapidly in the next few weeks.

8. What is the flutter for in the H2 valve

The H2 valve is a piezoelectric valve that normally operates in a full open/full closed condition (although a small degree of analog operation is available). It is felt that operation of the valve in a pulse modulated mode will offer the greatest degree of noise immunity and pressure control. This valve (and its controller) has been under development for several months and is now ready for testing with a source.

9. There was no mention of the concept of delivery of xenon into the LEBT.

Xenon will be delivered to the LEBT by means of a regulator and flow control valve. Determination of the flow rates and entry point into the LEBT of the xenon are experiments that need to be conducted.

10. What are the pressures in the various parts of the injectors?

Several different pressures were discussed in the criteria document. The document will be upgraded in an attempt to reduce the ambiguity. The following pressures and/or partial pressures are standard in the ATS injector:

Arc Pressure	2-3 torr	Hydrogen
	See below*	Cesium

*The cesium partial pressure is adjusted by control of the oven temperature and arc parameters so that about 3/4 of a monolayer of cesium resides on the arc electrode surfaces in the region of the arc.

LEBT pressure	5E-7 torr ultimate with no residual gases supplied.
	5E-6 partial pressure of hydrogen background
	5E-5 partial pressure xenon necessary to achieve neutralization. The partial pressure of xenon is critical.

11. Several different shutdown times and rise times of the system are quoted in the Criteria Document. Which of these is correct?

There are several numbers that may be quoted for rise and fall times of the system. Some parameters will have to be determined experimentally.

Hydrogen pressure rise in arc region

Rise	Experimental determination (ED)
Fall	ED

Arc temperature stabilization	ED

Extractor Voltage

Rise	4.7 μ sec
Fall	23.3 μ sec
Crowbar	7.5 μ sec*

Dome Voltage

Rise	114 μ sec
Fall	1700 μ sec
Crowbar	150 μ sec*
	can be reduced by factor of 10

Output beam

Rise	~ 10 microsec	neutralization buildup
Fall	load dependent	extractor fall time

12. Questions as to the survival of electronics in the dome.

Equipment must be located in the dome. Since it must be located there, sufficient shielding must be provided to yield a acceptable lifetime for the equipment. Locating equipment on long booms to try to give distance shielding to the equipment is not viable since first, on ISE, the long protuberances would be mechanically unstable and would be a hindrance in maneuvering the entire package. Moreover, the long leads would provide additional capacitance, would have to be charged, and would lead to additional electrical shielding problems.

13. Concern was registered about the radiation levels that will be encountered in the injector vicinity and the effect on the lifetime of the electronics.

14. What will be the radiation environment at the electronics package?

The latest calculations show that, with the experiments under consideration in the beam sensing region, the significant gamma and neutron fluences will be present. The latest calculations are by T. Stratton. Neutron damage will be the first effect noted. That damage will begin to occur between 12 and 120 weeks of operation. Detailed considerations of the tradeoffs between limited lifetime design and remote location of the equipment will be made as the design of the system evolves. Location of the electronics equipment within the vault at the injector should not present a major problem to the operation of GTA-1.

The issue of operational safety was raised through a couple of comments. I feel that a careful distinction between the form and function of safety controls should be made and that the question of safety includes both people and machine issues.

15. There should be administrative control and not computer control.

The functioning of administrative control is dependant on the operator (administrator) having information available. In GTA control design, most of the machine operating and condition parameters are stored in the computer.

16. Personnel safety cannot reside in the computer.

The ultimate responsibility for personnel safety will have to reside with the machine operator. However, the operator can only assume this responsibility if the operator has the condition of the machine available, and much of that information is provided by the computer. The question of safety goes beyond the issue of personnel safety and includes the safety of the machine. This includes orderly shutdown and normal operation of the machine. Since the system is proposed as an automatic machine under computer operation, the question of machine safety resides to some extent in the computer.

17. Crowbar or injector shutdown. Is 10 microsec short enough to prevent damage?

As in the case of beam start up, several times are quoted for shutdown. It is expected that the extractor circuit will shut down in about 10 microsec under normal operating conditions. If an arc-over is detected in the column or dome, the power supply capacitors can be shorted in about 100 ns. In any event, only about 10 J of energy will be available to produce damage.

18. What is the focus electrode function? Is it a form of beam steering?

In its traditional form at ATS, what is now called the focus electrode was intended as an electron supression electrode. By experimentation it was found to act primarily to change the focal position of the beam, hence the name change. It will provide little or no beam steering function.

LEBT Design

19. Will there be a control system to position of the LEBT magnets?

Yes. The details of the positioning system and the extent of the controls are now under discussion.

20. Is consideration being made as to the mechanical stability of the quads during launch conditions.

The mechanical stability of the quads is a concern that is being addressed. Since the quads are intended to be movable, the magnetic forces between the quads are of as much, or more, concern than the possible launch loads. When we have successfully solved the problem of magnetic interactive forces between the individual quads, the question of launch loads will also be solved.

21. What is the required strength of the quad singlet in the 25 kV beam energy position.

The strength of that singlet is comparable to the quads used elsewhere throughout the system as shown by the TRACE calculations.

22. Could solenoids be used in the LEBT?

Solenoids have been considered in the ATS design and were considered for the GTA design. Using solenoids has two major drawbacks: first, solenoids provide far more chromatic aberration and, hence, emittance growth than pm quadrupoles; second, the current drain for a solenoid would begin to become prohibitive for ISE in terms of power requirements.

Beam Interactions

23. Does rf cavity filling occur with a changing beam and what are the rise times of the beam.

The output beam rise time of the injector will be in the range of 1 to 10 microsec as determined by the time required to reach an effective degree of neutralization in the injector. The only practical means of achieving a shorter rise time would be to provide a beam deflection mechanism at the output of the injector at the price of a drastic increase of the emittance of the beam.

24. Will the restriction of the injector current by use of a limiting aperture in the LEBT increase the difficulty of coupling to the RFQ?

The inclusion of a limiting aperture near the output of the LEBT will probably decrease the emittance of the beam to some extent. The perturbations of the emittance by this methods would be less than the perturbations that would result from other techniques such as varying slit size, extraction potential, etc. The only other means of reducing deposited energy without introducing other major perturbations would be to shorten the pulse length and that may not be possible beyond the limiting time necessary for achieving neutralization in the LEBT. In short, there is no "good" means of changing the output current of the injector. The experience from ATS is that a limiting aperture after the last LEBT quadrupole is probably the "best" means of controlling the output beam current. The effects of employing this method of beam current control will be determined experimentally.

25. Concern was expressed about the sensitivity of the beam optics to variation of beam current fluctuations and the variation of the beam current for alignment and full power.

The present plan is to limit the current to 20% of maximum during alignment by placing an aperture at the output of the LEBT after the last quadrupole. This will make a small change in the neutralization and hence, some change in focus; however, it is felt that the changes can be compensated for by moving the pm quadrupoles. Since the restriction of beam current is being made after the last focusing elements, the beam optics will not be otherwise affected.

The present source at ATS produces current variations of around 5% (low 2%, high 10%) with a power spectrum extending up to 50 kHz. The effect of the emittance growth at constant neutralization due to current fluctuations will be examined. An attempt to control the beam focus and emittance growth by an active focus element will be considered; however, I am certain that such an approach may produce a study that is not within the time constraints of GTA-1.

26. Has feedback current regulation of the beam current been considered?

To my knowledge it has not been tried. The problem is that the noise in the output current is primarily due to plasma oscillations in the arc source. There are no external parameters at present that will allow control of this noise. If there are good suggestions for experiments in this area, they will certainly be tried.

27. Is the quoted power requirement for the arc correct?

The power required during arc start up may be around 600 volts at 100 amps and, during running, about 100 volts at 100 amps are in the range of the voltages and currents that have been used in the past. The point is that during the start up period, the question is of bringing the temperature up to the operating range so that the percentage of the surface area of the arc electrodes is covered with cesium. Depending on the flow rates of hydrogen, the exit slit size, and the extraction voltage, it takes around 100 - 200 watts of time averaged power to maintain the electrodes at the correct operating range for an ATS-type source. The actual power (voltage and current) requirements of the BEAR design source will have to be experimentally determined. The early experiments with the BEAR source will be invaluable in bringing the GTA source into operation.

28. Digital levels in the criteria document are listed as TTL positive true. It was recommended that this requirement be changed to the TTL negative true.

Change noted and design will be toward this goal.

29. Standard Camac is 12-bit digitization.

The signal resolution presented in the criteria document is the minimum resolution that we feel is required for operation. A greater resolution, while not necessary, is acceptable especially if it means that standard off-the shelf components can be used. The details of the interface between the injector and I&C are now under active negotiation.

30. Dome instrumentation temperatures were recommended to be 20°C + 5°C rather than 30°C to 40°C.

Change noted and design will be toward this goal.

31. Will the ventilation provided be adequate.

Purging of insulating gases will have to be done in a controlled manner separate from the operation of the ventilation of the system. A hydrogen leak into the vault during operation of the system may be cause for a shutdown, depending on the volumes that could leak. Venting of the cryos during regeneration must be considered on a separate basis since there could be an explosion hazard during that operation. The ventilation provided for other purposes should be adequate.

32. How would the extractor heater be powered.

Since heating elements with a voltage holdoff of 25 kV will be difficult to obtain, the element will be powered through an isolation transformer.

33. Have beam position monitors been considered for use in the injector?

Several beam diagnostic techniques are under consideration although Faraday cups and emittance scanners are the only ones discussed. The intent is to include as much diagnostic equipment as possible, subject to the time constraints of getting the system into operation in the allowable time. Two of the monitors built by Doug Gilpatrick will be tailored to the requirements of the injector, and they will be tried. However, most of the existing BPM's are designed to detect micropulses that do not exist in the injector. It is not certain how well existing monitors can be adapted to the "pulsed dc" beam in the injector.

34. Will provisions be made for changing the source canister in an inert atmosphere?

Since cesium is highly reactive and it will be trapped in a controlled manner on the acceleration electrodes, a means of providing an inert atmosphere must be provided during source cartridge changeout. If proper shutdown procedures are followed, there should be little cesium remaining in the canister after shutdown. Cesium hydroxide formation on the surfaces of the equipment after a period of operation, followed by exposure to the atmosphere, will be a hazard that will have to be considered; however, the hazard is on a par with working with other strong bases such as sodium hydroxide.

35. Where will be gate valve that separates the injector from the RFQ be located?

The location of this valve runs into competing requirements and it has not been exactly defined yet. It would be desirable to locate the beamline gate valve at the wall of the RFQ so that all components of the injector would be accessible. This position conflicts with the need to place the output quadrupole elements as close to the RFQ match points as possible (as shown by the beam calculations run by Oona) and the desire to make beam diagnostic measurements (in particular the emittance scans) as close to the match point as possible. The most probable compromise will be to place the gate valve immediately upstream from the projection quads.

Comments and recommendations from RFQ CDR

) The DTL may have to run at exactly 425 MHz; therefore, the RFQ needs some dynamic tuning capability because it must run at exactly the same frequency as the DTL.

The RFQ will have adequate dynamic tuning capability for operation at 5% duty factor, through the use of variable coolant temperature.

) Copper-plated steel vane tips are not recommended due to difficulties experienced on the ATS RFQ with electrical arcing. Solid copper vane tips should be used instead of copper plated.

The conceptual design showing copper-plated mild steel vanes has been changed. The current design will use copper-clad steel vanes that have 2 in. of high purity oxygen-free copper explosively bonded to a steel base For thermal reasons, the skirt sections will also be copper and clad steel.

) A full-scale cold model of half length is planned. Due to the relation between length and tuning (tuning difficulty increases with the square of length) shouldn't a full length model be built?

The machining costs will be somewhat greater for a full-length model but the extra information is important; a full length cold-test model will be built as soon as possible.

) Why not make the vanes and skirt sections out of aluminum?

Aluminum is not known for long term stability such as is required for proper operation of an RFQ that has as small an aperture as the current GTA RFQ physics design. The required vane tip spacing must stay within ±0.0004 in. of the tuned dimension over the 102 in. length of the vanes, during the operational life of the machine. Since our design team has little experience with designing aluminum structures, we have elected to use steel as the substrate.

5) The rf drive loop assembly should be coated internally with titanium nitride to reduce the possibility of multipactoring.

Titanium nitriding of drive loops is common practice and will be specified on the fabrication specs for the GTA RFQ drive loops.

6) The ATS RFQ also uses the gun-drilled cooling passages and had difficulty with breaking through the tank wall during fabrication. How will this be prevented?

The GTA RFQ will require 1/2-in. holes drilled lengthwise for cooling. The holes will be drilled in the machining blanks before any other work is done, and if necessary, small adjustments can be made to center the finished part around the holes. Reputable gun drilling shops routinely drill twice as deep as required here in sizes larger than 3/8 in. and will usually guarantee drill drift of no more than 0.001 in. per inch depth.

7) The RFQ design shows two 1-5/8-in. rf drive loops positioned in opposite quadrants. The power required is about 270 kW per loop; is this too much power for such a small coaxial line?

There is some disagreement on the power carrying ability of a 1-5/8-in. coaxial line in high vacuum (1.0e-7 torr). The question will be addressed by a high-power test to be performed on a proposed loop design. The mechanical design differences to the RFQ are trivial, but the rf system hardware is more involved for more loops (extra power splitters and phase shift devices). The RFQ design drawings can easily be modified to show four loops if tests prove that they are required.

GTA DTL CONCEPTUAL DESIGN REVIEW
COMMENTS AND ANSWERS

1. QUESTION: What is rf drive input: 6 1/8 in. coax? 500 kW or 1 MW?

   ANSWER: 500 kW with 6 1/8 in. power coax is primary design. A 1 MW drive loop option is also being studied.

2. QUESTION: Is tuning range with rotary tuner adequate?

   ANSWER: The rotary tuner in a given tank will be used in conjunction with the slug tuners. The overall tuning range will be adequate.

3. QUESTION: What are the design operating temperatures for the RGDTL and DTL sections?

   ANSWER: The operating range will be 70-75° F. Within this range the temperature will be controlled to ±0.5° F.

4. QUESTION: Is 54 in. the optimum beamline height from the floor?

   ANSWER: No. The best beamline height has been set at 60 in. and approved by the Project Office.

5. QUESTION: Are turbopumps required only for leak check?

   ANSWER: No. Also for initial pumpdown and backup pumping of certain outgas products.

6. QUESTION: What radiation shielding is required for TV viewports?

   ANSWER: Lead covers will be required on unused viewports and on the rf driveloop ports.

7. QUESTION: What information is needed to adapt RGDTL tank to AIS?

   ANSWER: None. The AIS buncher and downstream end walls will fit directly onto the RGDTL. Only the downstream endcup must be rebuilt to accomodate the higher energy output and 3° face angle of the RGDTL.

8. QUESTION: What is the impact of the increased quadrupole fringe field due to increased bore diameter?

   ANSWER: PARMILA runs of the beam through the various bore diameters shows no problems from fringe fields.

9. QUESTION: How much beam steering is required in the DTL and where should steering magnets be located?

ANSWER: This has not yet been determined although several steering options exist, including magnets inside the drift tubes, in the intertank spacers, and around the tanks.

10. QUESTION: What are the rf seal problems and potential solutions?

ANSWER: Improperly seated seals and overheating seals. Solutions are to assure seal integrity through proper installation and to maintain adequate cooling around seals. The C-seals will function properly under these conditions at 5% duty factor.

11. QUESTION: Will DT stem design meet launch loads of mechanical and acoustical vibrations? What are analytical calculations and experimental tests needed to resolve this issue?

ANSWER: Analysis has shown that single stem support can withstand launch loading on all but the heaviest, i.e., highest energy, drift-tube bodies. On these, a simple enlargement of the stress pad at the base of the stem will suffice. Since GTA-1 will fundamentally be a physics experiment rather than a design to test space compatability, concern over hard point socketing, which would assure vibration rigidity, has receeded. We now have solutions to the problem but will only apply them in a limited way in the interest of high grade physics. The main conclusion, however, is that single stem supports can withstand launch vibrations with only modest modifications to the existing design.

12. QUESTION: Should the DT weld be moved to a lower electric field region?

ANSWER: The weld has been moved to the outside of the DT body and away from the high electric field region.

13. QUESTION: Would getter pumps inside the DT's be useful?

ANSWER: No, there is no room for such devices in the DT's.

GTA COOLING SYSTEM CONCEPTUAL DESIGN

Review Comments and Answers

1. Question: Is temperature the only knob for tuning RFQ?

   Answer: Once the RFQ has been machined and set in place, cooling water temperature will be the only "tuning knob."

2. Question: How do you start up system to purge air and fill pipes?

   Answer: Airbleed valves will be located in system high spots.

3. Question: How far down does auto control system go?

   Answer: This is pending design information from other systems.

4. Question: What indication is available when a hose breaks?

   Answer: A line burst sequence on a hard wire "fail-safe" circuit is under consideration and will be determined by preliminary design review.

5. Question: What temperature measurements are available which will provide information directly for ISE (e.g., temperature gradient, total heat load, etc.)?

   Answer: The up-to-date information available is shown in the table on vu-graph #3 of cooling system section.

6. Question: Should H° BS include H^+ and H^- beam stops?

   Answer: Yes

7. Question: Is cooling adequate for 5% DF for Injector RFQ and DTL?

   Answer: Yes, for conditioning and in test mode.

8. Question: Who is responsible for making sure outlet valve is open when inlet valve is opened or are these interlocked?

   Answer: This will be defined under system start up and shut down sequence.

9. Question: What is water quality required for carbon steel?

   Answer: Samples have been taken from an existing system at FMIT and requirements will be dependent on future analysis.

GTA VACUUM SYSTEM CONCEPTUAL DESIGN
REVIEW COMMENTS AND ANSWERS

1. COMMENT: Use a WS 152 Roots blower instead of a WSU 1000 blower for the conditioning flow on the injector. The WS 152 can handle a flow rate of 50 sccm, which is sufficient for conditioning and is a cleaner, two-stage pump.

   RESPONSE: C. Mansfield agreed that a flow rate of 50 sccm is adequate. The WS 152 is now the baseline pump for injector conditioning.

2. COMMENT: Consider using 10 in. pumps on telescope and beam sensing, possibly reducing the number of pumps from 10 to 4 each.

   RESPONSE: The design is still evolving: if the foil neutralizer is adopted, the pumping requirements will decrease and 8 in. pumps will be more attractive.

3. COMMENT: Gauging must be provided in each subsystem to permit monitoring of pressures up to ambient. Recommend a mechanical type such as the MKS "Baratron".

   RESPONSE: Gauging will be provided in each subsystem. Orientation and species sensitivities will not preclude the use of a gauge such as the CONVECTRON since these characteristics are known and can be dealt with.

4. COMMENT: The response time, (V/S) of each subsystem high vacuum system should be less than 100 ms. This is important in conditioning recovery from gas bursts.

   RESPONSE: This value is not attainable in the present accelerator design. The system was designed to attain a pressure of 10^{-6} or less based upon material offgassing and outgassing properties. If, instead, the machine were to be designed to achieve a time constant of 100 ms, an approximate quadrupling of the number of pumps would be required in the accelerator sections.

5. COMMENT: The use of ZrAl getter pumps on each drive loop is unnecessary. Calculations indicate a very small gas load in the drive loop which can easily be pumped by the main pumps.

   RESPONSE: High vacuum is felt to be very critical for the drive loops. Some getter pumps will be kept available to be used only if there is a problem. This approach is felt to be necessary by the subsystem designers.

6. COMMENT: Use rotatable ASA flanges instead of using the ISO multi-flange as the adapter from rotatable to non-rotatable. These are available commercially from NOR-CAL.

RESPONSE: This will be done. Problems exist in fitting the ISO multi-flange to some tube-bored ANSI sizes. Switching the standard to rotatable ASA types like those commercially available from NOR-CAL will solve this problem.

7. COMMENT: Can pumps be acceptance tested at the vendor's facilities to avoid uncrating, testing, and recrating?

RESPONSE: Yes, this has been incorporated into the purchase requests for the pumps.

8. COMMENT: A purge line is needed to speed up regeneration.

RESPONSE: Either electric heaters or purge gas are needed for regeneration. If the pumps we buy don't have electric heaters, we will add a purge line to each pump.

9. COMMENT: Use a flange with an O ring groove because the groove is less vulnerable to scratching.

RESPONSE: Pumps have been ordered with O-ring grooves: this greatly reduces the possibility of scratching since the pumps will probably be the most handled component.

10. COMMENT: Make the warranty period begin when the pumps are placed in service.

RESPONSE: This was attempted but added greatly to the complexity of placing the purchase order. The warranty now begins at delivery at MAI's request.

11. COMMENT: Because of space limitations, we may not have valves between the LEBT, RFQ, buncher and linac tanks 1 and 2. Therefore, we may have to pump these components simultaneously.

RESPONSE: This need not change the design or design philosophy of the vacuum system since there are high impedances between these components. Each should have the capability to pump separately, although the absence of valves means their activities must be coordinated.

12. COMMENT: Can cryopumps carry the load by themselves if the turbos shut down due to a brief overpressure?

RESPONSE: The most closely matched pump/load ratio occurs in the linac where there is approximately 50% excess pumping capacity. Should the turbos shut down, the cryopumps would be capable of handling the load based upon conservative estimates of offgassing rates. It should be noted that the cryopumps will still not be operating at capacity since they are conductance limited in their installation on linac.

13. COMMENT: A thermocouple or convection gauge is needed in each cryopump to control start up and regeneration.

RESPONSE: There will be a thermocouple or convection gauge in each cryopump.

14. COMMENT: We need to consider how the regeneration times of the cryopumps affect the operating cycle of the machine.

RESPONSE: The most critical area (shortest operation between regenerations) is the injector which adds about one std. liter of hydrogen to the pump per day. Each pump has a capacity for hydrogen of 27 std. liters and there are two pumps which have a combined capacity of 54 std. liter. This means we can operate for 54 consecutive days without stopping for regeneration. Therefore, cryopump regeneration will have a minimal effect on the machine's operating cycle.

15. COMMENT: Can wiring and control panel complexity be reduced by using computer controls and computer generated displays?

RESPONSE: The control system must allow separate "stand alone" manual control of each subsystem at local operating stations. Some interlocking of valve position, pressure levels, and pump status will be needed to protect pumps and machine. The control system must not be dependent upon the central computer to perform its functions.

16. COMMENT: All pumps with motors shall be ordered with 480 V, 3ϕ motors if at all possible.

RESPONSE: This has been done except for cryopump compressors and mechanical pumps for which 208 V, 3ϕ motor has been specified. For the turbopumps, 208 V, single phase power has been specified.

17. COMMENT: What information will be supplied to ISE?

RESPONSE: Gas loads during nominal beam operation will be supplied to ISE. Also, the effects of off nominal operations on the pumping system will be supplied.

18. COMMENT: Why are so many flange sizes specified? Can we get by with 2-3 sizes?

RESPONSE: Early design information from the telescope, neutralizer, and beam sensing indicates the need for many different diameters ranging from 2 in. to 24 in.

19. COMMENT: How much outgassing do you expect from diagnostics and beam "Halo"?

RESPONSE: Detailed outgassing calculations will be performed for all diagnostics and we will attempt to estimate the effects of beam "Halo".

20. COMMENT: Specify cleaning and assembly procedures for all vacuum connected subsystems.

RESPONSE: This shall be done.